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द्रव चालित टरबाइनों के माडल स्वीकरण परीक्षण की संहिता

Indian Standard

CODE FOR MODEL ACCEPTANCE TESTS OF HYDRAULIC TURBINES

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Indian Standard

CODE FOR MODEL ACCEPTANCE TESTS OF HYDRAULIC TURBINES

CHAPTER I — OBJECT AND SCOPE

The purpose of this code is to establish arrangements for the preparation and execution of laboratory model tests, as well as to evaluate the results obtained so that the hydraulic performance of a model turbine and of the corresponding prototype turbine can be ascertained.

1. Types of turbines

In general the code applies to any type of hydraulic reaction or impulse turbine tested under laboratory conditions.

2. Excluded topics

2.1 This code excludes all matters of purely commercial interest except those inextricably bound up with the conduct of the acceptance tests.

2.2 This code is not concerned with the structural details of the turbines nor with the mechanical properties of their components, so long as these do not affect model performance.

2.3 Model tests for research performance are not specially dealt with in this code. It is recommended, however, that equipment and methods described in the code be applied in the current testing work in the laboratory, to keep it prepared for acceptance tests.

CHAPTER II — TERMS, DEFINITI SYMBOLS AND UNITS

1. Measuring systems

The metric system of units is adopted throughout the code but other systems shall be allowed if preferred.

The terms, definitions, symbols and units adopted in this code are listed below:

2. List of terms

Term		Definition	Symbol	Units
2.1	*Rate of flow or discharge*	Volume of water per second passing a specified section.	Q	m^3/s (ft^3/s)
2.1.1	Turbine discharge	Volume of water used by the turbine per second, including leakage water in stuffing boxes and turbine thrust relief pipes but excluding water required for operation of the dynamometer auxiliary machinery and for cooling of bearings.	Q	m^3/s (ft^3/s)
2.1.2	Guaranteed discharge	Turbine discharge at guaranteed head, output and speed.	Q_r	m^3/s (ft^3/s)
2.1.3	No-load discharge	Turbine discharge at no-load and normal speed and guaranteed head.	Q_0	m^3 · (ft^3/s)
2.2	*Area* (see Figures 1 to 4)	Cross-sectional area normal to the general direction of flow.	A	m^2 (ft^2)
2.2.1	Area at turbine inlet	*a)* In plants with open flume, the area of the agreed section downstream of turbine inlet screen. *b)* In plants with closed conduit, the area of section through the agreed measuring point near the turbine casing downstream of inlet valve.	A_1	m^2 (ft^2)
2.2.2	Area at turbine outlet	In reaction turbines, the area of draft tube cross-section normal to the flow at the outlet end of the draft tube must be mutually agreed. In plants not having a typical draft tube, the location of the outlet section must be mutually agreed upon. In impulse turbines, the area of cross-section at outlet cannot be defined and is assumed infinitely large.	A_2	m^2 (ft^2)
2.3	*Mean velocity*	Rate of flow divided by area of cross-section: $v = Q/A$	v	m/s (ft/s)
2.4	*Pressure*	The pressure at any point in the system expressed as force per unit area.	p	kp/cm^2 (lbf/in^2)

Term		Definition	Symbol	Units
2.4.1	Gauge pressure	The reading given by a gauge of the pressure at any point in the system.	p_g	kp/cm² (lbf/in²)
2.4.2	Pressure at inlet to turbine	The gauge pressure at the inlet measuring point corrected for the elevation of gauge.	p_1	kp/cm² (lbf/in²)
2.4.3	Pressure at outlet from turbine	The gauge pressure at the outlet measuring point corrected for elevation of gauge.	p_2	kp/cm² (lbf/in²)
2.5	*Specific weight of water* [1]	The weight in air of unit volume of water used by turbine.	γ	kp/dm³ (lbf/ft³)
2.6	*Head*			
2.6.1	Pressure head	The head of water equivalent to the pressure at any point in the system.	h_p	m (ft)
2.6.2	Velocity head	The head equivalent to the square of the mean velocity divided by twice the acceleration of gravity: $h_v = \frac{v^2}{2g}$ [2]	h_v	m (ft)
2.6.3	Potential head (Geodetic head)	Elevation of a measuring point above mean sea level or other reference datum.	z	m (ft)
2.6.4	Total head	The sum of potential head, pressure head and velocity head, in a given section: $h_t = z + h_p + h_v$	h_t	m (ft)
2.6.5	Net head	The head available for doing work on the turbine; it is the difference between total head at inlet and outlet. (See illustrative examples shown in Figures 1 to 4.)	H_n	m (ft)

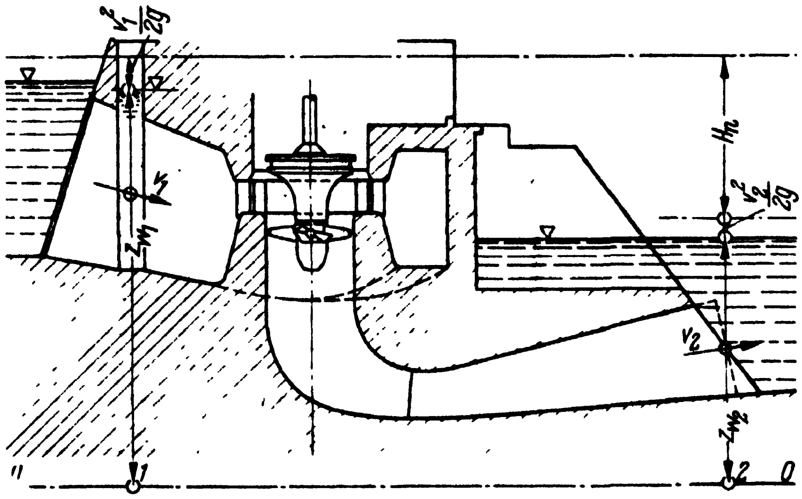

FIG. 1. — Reaction turbine (Francis, Propeller, Kaplan). Rectangular spiral casing in concrete; draft tube bend.

$$H_n = (z_{w1} - z_{w2}) + \frac{(v_1^2 - v_2^2)}{2g}$$

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[1] See tabulated values of γ at end of this chapter, Table I.

[2] See tabulated values of g at end of this chapter, Table II.

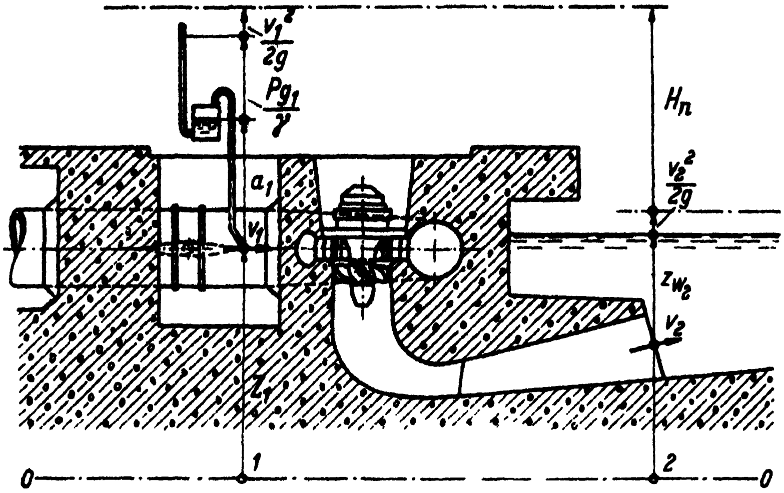

FIG. 2. — Reaction turbine. Spiral casing with circular section.

$$H_n = (z_1 + a_1 - z_{w2}) + 10 \cdot \frac{p_{g1}}{\gamma} + \frac{(v_1^2 - v_2^2)}{2g}$$

(metric)

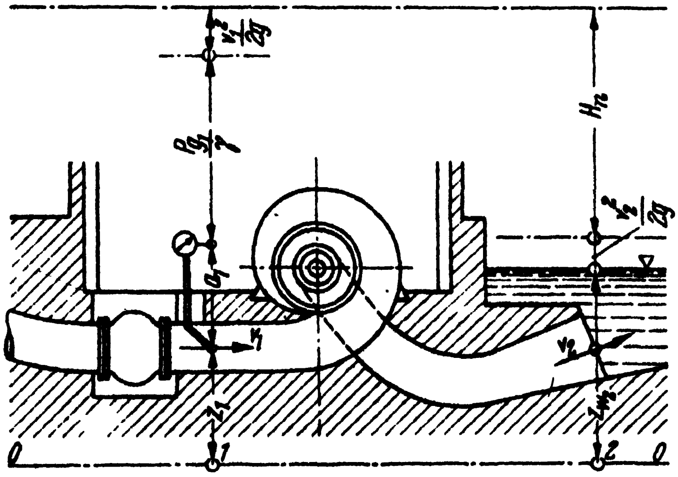

FIG. 3. — Reaction turbine. Horizontal shaft.

$$H_n = (z_1 + a_1 - z_{w2}) + 10 \frac{p_{g1}}{\gamma} + \frac{(v_1^2 - v_2^2)}{2g}$$

(metric)

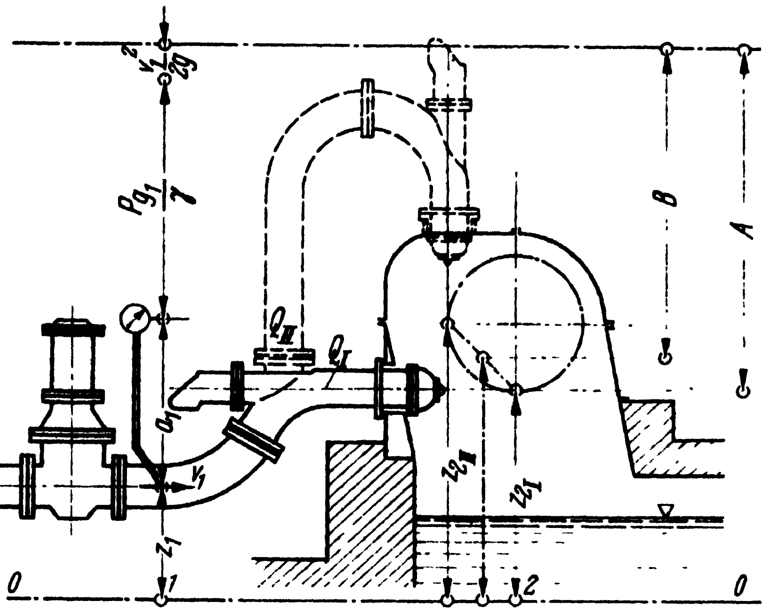

FIG. 4. — Impulse turbine.

A: Single nozzle

$$H_n = (z_1 + a_1 - z_2) + 10 \cdot \frac{p_{g1}}{\gamma} + \frac{v_1^2}{2g}$$

B: Twin nozzle

$$H_n = \frac{Q_I}{Q_I + Q_{II}}(z_1 + a_1 - z_{2I}) + \frac{Q_{II}}{Q_I + Q_{II}}(z_1 + a_1 - z_{2II}) + 10 \cdot \frac{p_{g1}}{\gamma} + \frac{v_1^2}{2g}$$

(metric)

Term		Definition	Symbol	Units
2.6.6	Guaranteed head	The net head for which the turbine is ordered.	H_r	m (ft)
2.6.7	Loss of head	Loss of total head between any two sections.	H_l	m (ft)
2.6.8	Height of measuring instrument	The difference in elevation between the datum for which the measuring instrument is calibrated and the location of the measured point.	a	m (ft)
2.6.9	Barometer height	The height of the water barometer corresponding to the atmospheric pressure at the corresponding temperature.	h_b	m (ft)
2.6.10	Vapour pressure	The height of the column of water corresponding to the vapour pressure at the temperature of the test water.	h_{va}	m (ft)
2.6.11	Geodetic suction head	Height of turbine or runner above tail-water level (see Figure 5).	h_s	m (ft)

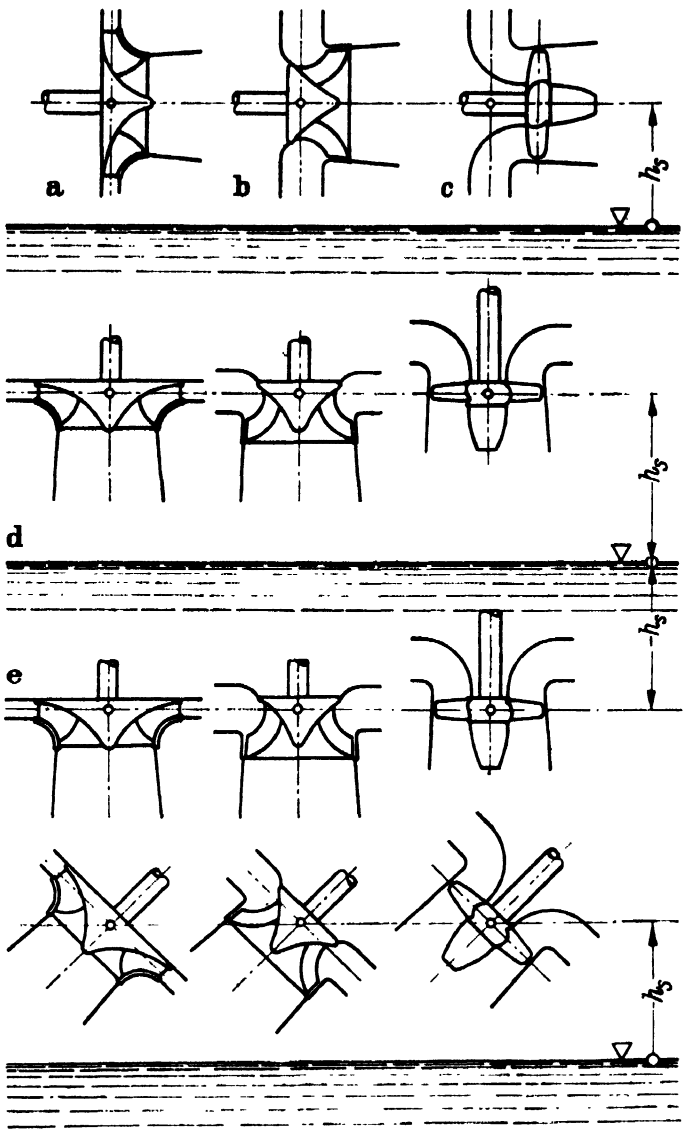

FIG. 5. — Definition of geodetic suction head h_s.

a) Francis low specific speed
b) Francis high specific speed
c) Kaplan, Propeller
d) positive suction head
e) negative suction head

▽ Tailwater level

Term		Definition	Symbol	Units
2.7	*Input and output*			
2.7.1	Turbine input	The hydraulic power equivalent of the turbine discharge Q at net head H_n: $P_d = k \cdot \gamma \cdot Q \cdot H_n$ $\left(k = \frac{1\,000}{102}\right)$ (or $k = \frac{1\,356}{1\,000}$ foot pound system)	P_d	kW
2.7.2	Turbine output	The mechanical power delivered by the turbine shaft.	P_t	kW
2.7.3	Guaranteed output	The turbine output at guaranteed net head H_r and guaranteed speed n_r for which the turbine is ordered.	P_r	kW
2.8	*Efficiency*			
2.8.1	Turbine efficiency	Ratio of turbine output to turbine input.	η_t	%
2.8.2	Turbine weighted average efficiency	The weighted average efficiency computed arithmetically from the single values: $\eta_1, \eta_2, \eta_3, ...$ at the guaranteed output or discharge values and at their respective weights: $w_1, w_2, w_3, ...$ agreed for these outputs or discharges by: $\eta_{t_w} = \frac{w_1 \cdot \eta_1 + w_2 \cdot \eta_2 + w_3 \cdot \eta_3 + ...}{w_1 + w_2 + w_3 + ...}$	η_{t_w}	%
2.8.3	Turbine arithmetical average efficiency	Weighted average efficiency as defined in 2.8.2 with $w_1 = w_2 = w_3 = ... = 1$	η_{t_a}	%
2.8.4	Turbine planimetric average efficiency	The mean height of the efficiency curve within the guaranteed range.	$\eta_{t_{pl}}$	%
2.9	*Speed*	Number of revolutions per unit time.	n	rev/min
2.9.1	Guaranteed speed	The speed for which the turbine is ordered.	n_r	rev/min
2.9.2.	Runaway speed	The maximum speed attained when all load is removed, that is at zero torque on the runner, and when the supply of water is unchecked in such a position of guide vanes (and runner blades of Kaplan turbines) which gives maximum runaway speed.	n_R	rev/min
2.10.	*Cavitation*	In model testing cavitation (the formation of vapour bubbles due to low local pressure) may be directly viewed through suitable observation ports.		

3. Clarifications

Clarification of any term, definition or unit of measurement in dispute shall be agreed to in writing by the contracting parties in advance of the test.

TABLE I

*Variation of γ, the specific weight of water *, with latitude, temperature and height above mean sea level*

Latitude	Specific weight of water γ in kp/dm^3 Water temperature in °C					
	0	4	10	20	30	40
At sea level						
0	0.996	0.996	0.996	0.994	0.992	0.988
10	0.996	0.996	0.996	0.995	0.992	0.989
20	0.997	0.997	0.996	0.995	0.992	0.989
30	0.997	0.997	0.997	0.996	0.993	0.990
40	0.998	0.998	0.998	0.997	0.994	0.990
45 approx.	0.999	0.999	0.998	0.997	0.994	0.991
50	0.999	0.999	0.999	0.997	0.995	0.991
60	1.000	1.000	1.000	0.998	0.995	0.992
70	1.001	1.001	1.000	0.999	0.996	0.993
At 1 000 m						
0	0.996	0.996	0.996	0.994	0.992	0.988
10	0.996	0.996	0.996	0.994	0.992	0.988
20	0.996	0.997	0.996	0.995	0.992	0.989
30	0.997	0.997	0.997	0.995	0.993	0.989
40	0.998	0.998	0.998	0.996	0.994	0.990
45 approx.	0.998	0.999	0.998	0.997	0.994	0.991
50	0.999	0.999	0.999	0.997	0.995	0.991
60	1.000	1.000	1.000	0.998	0.996	0.992
70	1.000	1.000	1.000	0.999	0.996	0.993
At 2 000 m						
0	0.996	0.996	0.995	0.994	0.991	0.988
10	0.996	0.996	0.996	0.994	0.992	0.988
20	0.996	0.996	0.996	0.995	0.992	0.989
30	0.997	0.997	0.997	0.995	0.993	0.989
40	0.998	0.998	0.998	0.996	0.994	0.990
45 approx.	0.998	0.998	0.998	0.996	0.994	0.991
50	0.999	0.999	0.999	0.997	0.994	0.991
60	1.000	1.000	1.000	0.998	0.995	0.992
70	1.000	1.000	1.000	0.999	0.996	0.993
At 4 000 m						
0	0.995	0.995	0.995	0.993	0.991	0.988
10	0.995	0.995	0.995	0.994	0.991	0.988
20	0.996	0.996	0.996	0.994	0.992	0.988
30	0.996	0.997	0.996	0.995	0.992	0.989
40	0.997	0.997	0.997	0.996	0.993	0.989
45 approx.	0.998	0.998	0.998	0.996	0.994	0.990
50	0.998	0.998	0.998	0.997	0.994	0.990
60	0.999	0.999	0.999	0.997	0.995	0.991
70	1.000	1.000	1.000	0.998	0.996	0.992

* Pure distilled water values corrected for buoyancy of air corresponding to International Standard Atmosphere (I.C.A.N.). This is for dry air, but corrections for humidity are not likely to alter the above values by more than ± 0.1 %.

TABLE II

Variation of the acceleration due to gravity " g " with Earth's latitude and height above mean sea level

Latitude	Height in metres above mean sea level			
	0	1 000	2 000	4 000
Degrees	m/s^2	m/s^2	m/s^2	m/s^2
0°	9.780 36	9.777 27	9.774 18	9.768 01
10°	9.781 91	9.778 82	9.775 74	9.769 57
20°	9.786 38	9.783 30	9.780 21	9.774 04
30°	9.793 24	9.790 16	9.787 07	9.780 90
40°	9.801 67	9.798 50	9.795 50	9.789 33
50°	9.810 65	9.807 57	9.804 48	9.798 31
60°	9.819 11	9.816 02	9.812 93	9.806 76
70°	9.826 01	9.822 92	9.819 83	9.813 66

The international standard value of " *g* " adopted by the International Commission for Weights and Measures is 9.806 65 m/s^2 corresponding approximately to latitude 45° and sea level.

CHAPTER III — NATURE AND EXTENT OF TECHNICAL GUARANTEES

1. General

A contract contains main guarantees for output and efficiency of a turbine and sometimes additional guarantees covering runaway speed and cavitation influence. Guarantees for speed variation, as well as vibration and cavitation erosion, are not normally checked by model tests.

The purchaser shall provide true, full and acceptable data respecting the waterways from intake to the tailrace, including all elements of the construction which are liable to influence hydraulic conditions of the turbine in operation. The extent of the water passages connected to the model turbine shall be stated and the inlet and outlet measuring sections clearly defined.

2. Main guarantees

When turbine acceptance is determined by model testing, the following methods of guarantee for prototype turbines are possible:

1. Guarantees based on model test results
2. Guarantees based on model test results with allowance for scale effect.

2.1 *Maximum output*

Guarantees of maximum output for the turbine may be made on the basis either of model tests with or without allowance for scale effects, or directly by means of field measurement of output under the guarantee head. In the latter case the chapter governing output measurements in the field test code of hydraulic turbines shall apply.

2.2 *Efficiency*

2.2.1 This test code applies to those cases where guarantees of efficiency are based upon a model test with or without allowance for scale effects. It shall be clearly stated whether guarantees are given for efficiencies under cavitating or non-cavitating conditions.

2.2.2 Efficiency guarantees may be based upon the model test results corrected for scale effect by a suitable formula. The formula should be agreed upon at the time the invitations for bids are issued. If no formula is agreed upon or specified in advance, the following scale-effect formula will be used:

Propeller and Kaplan turbines: Hutton formula

$$\frac{\text{prototype loss}}{\text{model loss}} = 0.3 + 0.7 \left(\frac{Re_m}{Re_p} \right)^{1/5}$$

$$\text{Where } R_e = \text{turbine Reynolds' number } R_e = \frac{D}{\nu} \sqrt{2g \, . \, H_n}$$

Subscript p denotes prototype

Subscript m denotes model

H_n = head — m or ft

D = runner diameter — m or ft

ν = kinematic viscosity of fluid in square metres per second (ft^2/sec).

Francis turbines : Moody Formula

$$\frac{\text{prototype loss}}{\text{model loss}} = \left(\frac{D_m}{D_p}\right) 1/5$$

Impulse turbines : no scale effect formula $\eta_p = \eta_m$.

Cam relationship of Kaplan turbines

In order to find the correct relationsship for the combination cam of prototype Kaplan turbines, it is necessary to supplement the model tests by means of a special test in the plant. This may be, for instance, an index test where head, speed, power, gate opening blades angle and an index of discharge are measured.

Other guarantees

1 *Runaway speed*

A guarantee may be made that the runaway speed of the prototype at a stated head will not exceed a specified value under the worst possible contractual operating conditions.

2 *Cavitation*

A hydraulic turbine may be affected by cavitation in different ways, but mainly alteration of performance characteristics and pitting of material. Guarantees may be given in both respects, but only the influence on performance can be checked by model tests, whilst the pitting development must be stated by observations at site.

CHAPTER IV — TEST CONDITIONS TO BE FULFILLED

1. Test plant

Test plants for conducting model acceptance tests must meet the following requirements:

1.1 *Condition of water*

The water shall be clean and clear and shall not contain solid ingredients. Free gas particles or air bubbles shall be removed as far as possible. The total air or gas content and the temperature of the water shall be measured. During each test run the change in gas content and in temperature shall be as small as possible. The highest temperature may not be more than 35 °C.

1.2 *Flow conditions*

1.2.1 *Model inlet*

The flow at the inlet of the model shall be free from vortices. In the absence of any agreement to the contrary, the tests will be carried out with a uniform distribution of water velocity upstream of the model turbine.

1.2.2 *Model outlet*

The discharge from the draft tube of the model turbine may not be artificially disturbed.

1.3 *Fluctuations during individual test runs*

Any fluctuation in head and in speed during an individual run with fixed opening should not exceed ±0.5% of the model test head and ±0.25% of the speed respectively.

1.4 *Measurement of the water discharge*

The water discharge is measured using one of the methods listed under Chapter VIII. It is preferable to calibrate the measuring equipment *in situ* under the prevailing test conditions. In particular the absolute pressures shall be identical under test and calibration conditions to avoid errors in the measurement of the water discharge caused by air bubbles. It is desirable to have another measuring method in order to check occasionally on the satisfactory operation of the water measuring equipment.

1.5 *Water losses*

Any change in the water discharge between the measuring section and the model turbine by reducing or adding to the water flow as well as any adding of air must be avoided. If the water inflow or outflow through the shaft gland is appreciable it must be corrected for.

1.6 *Heads*

1.6.1 *Heads and limits*

The model test head can be chosen within wide limits because the influence of head on the test results is negligible. It is only necessary for the Reynolds number to be high enough. For minimum head limits, see Sub-clause IV.2.1.

1.6.2 *Suction head and counter-pressure*

Although it is desirable to establish the efficiency of model turbines under cavitating conditions similar to the prototype, for practical reasons, it is more convenient to measure first efficiency under non-cavitating conditions. Subsequently, sufficient cavitation tests may be made to establish the influence of the cavitation parameter on performance. The suction heads in such tests should be adjusted to cover the conditions specified in the contract.

1.7 *Torque*

1.7.1 *Checking of Zero point and calibration*

With any of the measuring methods selected according to Clause X.2 for the measurement of the torque, it must be possible to check on the Zero point and to make a calibration in the entire measuring range.

1.7.2 *Moment of bearing friction*

The effective moment of the model turbine also includes the moment of bearing friction. This bearing friction must, therefore, be measured either together with the braking moment proper or separately (See Clause X.2).

1.8 *Speed*

The speed must be determined by a mechanical or an electrical counting mechanism. Additionally a direct-reading instrument may be used to check on the constancy of the speed.

2. Model similitude

The model turbine must meet the following conditions:

2.1 *Model scale and minimum size*

Minimum values are prescribed for the model runner diameters and for the model scale to ensure the required accuracy in manufacture and surface quality, in order to reduce the absolute value of the scale effect and to have a reasonable Reynolds' number. The requirements are as follows:

Type	Kaplan Propeller	Francis	Impulse
Re_{min}	2.10^6	$2.5. \ 10^6$	$3.5. \ 10^6$
	Where $R_e = D_s \dfrac{\sqrt{2g.H}}{\nu}$		$\dfrac{B\sqrt{2g\,H}}{\nu}$
$D_{s\,min}$ (draft tube)	250 mm (10 in)	250 mm (10 in)	B_{min} 80 mm (3 in) (bucket width)
H_{min} (testing head)	1 m (3.5 ft)	2 m (7 ft)	40 m (130 ft)

2.2 *Similarity*

2.2.1 *Geometric similarity of model and prototype*

If there is no other agreement to the contrary, the model turbine from the inlet up to the outlet must, in hydraulically effective parts, be geometrically similar to the prototype. A model turbine for acceptance tests is to include the turbine itself, the draft tube and turbine casing, the upstream limits of which normally should exceed twice the discharge diameter of the turbine runner upstream from the centre line of the runner.

Elbows, y-pipes, gates or valves or free surface upstream from the inlet should be included if they are likely to affect performance.

Only with respect to the sealing of the shaft is geometric similarity not imperative, e.g. in the model, clearances without any physical contact will be preferred, even if stuffing boxes giving rise to friction are used on the prototype.

2.2.2 *Surface conditions*

The hydraulically effective surfaces of the model turbine shall have the same relative roughness as those of the prototype.

2.3 *Checking the geometric similarity of model and prototype*

A check on the geometric similarity of model turbine and prototype is a basic requirement for acceptance tests on the model. At least the following parts must be checked:

- the principal dimensions of inlet and outlet of the spiral casing, of the distributor, of the runner and of the draft tube; for impulse turbines the principal dimensions of the runner buckets and of the housing;
- the number of stay vanes, runner blades and guide vanes; nozzles and buckets of an impulse turbine;
- the width of the runner and guide vane clearances;
- the form of the runner blades and of the guide and stay vanes; for impulse turbines the form of the buckets, of the nozzles and of the needles.

For checking the geometrical similarity of the model and of the prototype it is recommended:

With Francis turbines:

- to use 2 templates for the forms of the inlet profile of the blades;
- to use 1 template for checking the blade inclination at the runner inlet in the middle section;
- to check the mean clear width and area of the water passages at the runner outlet.

With propeller and Kaplan turbines:

- to use 2 templates for the form of the inlet profile of the blades;
- to use 2 templates for the blade suction side for an inner and an outer section;
- to check on the blade thickness of the selected blade sections on at least 3 points.

With impulse turbines:

- to use 2 templates for 2 sections of the bucket;
- to determine the bucket inclination with respect to the radial direction;
- to use 1 template for the form of the needle and the nozzles.

2.4 *Permissible deviations in geometric similarity between prototype and model*

When the deviations between the prototype and the model are compared, it must be considered that the manufacturing inaccuracies in percent of model and prototype add. In view of this, if there is no agreement to the contrary, the following deviations will be regarded as permissible:

(The percentages given below are percentages of the scaled-up model dimensions.)

Principal dimensions of hydraulic passages:	
— Unmachined parts (both metallic and concrete)	± 2 %
— Machined parts	± 0.2%
— Runner seal clearance, geometrically similar or half model scale	+ 0 % — 50 %
With Francis turbines:	
— The templates checking the radius of curvature at the inlet of the blades expressed in percent of the radius	± 5 %
— The template for the vane inclination	± 2°
— The mean clear outlet width taken as an average around the runner for each one of at least three measuring points	+ 3 % — 1 %
— Deviations of each individual outlet width from the mean value	± 10 %
— Maximum thickness of blade	+ 3 % — 10 %
With propeller and Kaplan turbines:	
— The templates checking the radius of curvature at the inlet of the blades expressed in percent of the radius	± 5 %
— The templates for the section through the blades referred to the maximum runner diameter	± 0.1%
— Inclination of inner and outer sections	± 0.5°
— Local blade thickness	+ 0.08 e + 2 mm (e local blade thickness in mm) — 0.04 e — 2 mm
With impulse turbines:	
— The templates checking the bucket form referred to the bucket width	± 1 %
— Bucket inclination	± 1°

— Discharge angle	± 2°
— Jet circle radius (referred to bucket width)	± 1 %
— Misalignment of jet on bucket (referred to bucket width)	± 1 %
— Templates for the form of the needle and nozzle referred to the nozzle diameter	± 0.2%

CHAPTER V — TEST PROCEDURE

1. Choice of laboratory

Any laboratory satisfying the stipulations of Chapter IV may be considered suitable for the execution of acceptance model tests.

2. Time for tests

The date for model tests covered by this code should be stated in the contract.

3. Personnel

The tests should be carried out by personnel having special experience with the particular test equipment used under the supervision of qualified representatives from each party. The latter shall in all respects have equal rights.

If, after special agreement between the parties, an independent expert may be called to act as chief of the test, he will in such a case take over full responsibility for the correct execution of the test and interpretation of the results in accordance with this code. He shall take all definite decisions, but has to receive for due consideration any remarks or suggestions by any of the parties' representatives.

4. Test programme

As the tests are being planned there shall be worked out in co-operation between the parties a detailed technical programme. This programme shall, with reference to the contract guarantees, give particulars concerning the following items:

4.1 *Type of test*

It shall be stated whether the test is to cover cavitation tests in addition to the ordinary efficiency measurements and other measurements (runaway speed, etc.) under non-cavitating conditions. The cavitation test may be a separate test for determination of the complete cavitation characteristic curves.

4.2 *Extent of test*

A stipulated minimum number of test points for the same setting are to be concentrated with suitable spacing within speed limits corresponding to the desired range. The number of runs for each test point shall be chosen in accordance with Clause VI.4.

4.3 *Measuring instruments*

There may be two or more measuring instruments for the same quantity, but only one shall be considered valid. Another instrument may be read off for reference only. The correct functioning of the valid instrument may be checked in this way. The selected instruments shall be clearly indicated in the programme.

5. Inspection

The model turbine shall be inspected and accurately measured with respect to its geometrical shape and dimensions (see Chapter IV) before any test is started. The true indications of all scales for the position of blades and wicket gates and of the needle setting shall be included and all essential figures entered in the records.

The complete test circuit with its instrumentation also has to be thoroughly checked. Special attention should be paid to discharge measuring devices and pressure tappings.

6. Calibration

In connection with the inspection complete calibrations shall be made of all measuring instruments. It is recommended that all adjusting screws (on instrument scales, dynamometer arm, etc.) then be sealed. This will exclude later uncertainty and discussion about the proper position of such elements. The calibrations shall be repeated after the main test has been finished. If the calibration after test differs by less than the inaccuracies listed in Clause VI.3. the original calibration shall be used for computing results. If the calibration differs by more than the amount listed in Clause VI.3. the test shall be deemed invalid.

Any one of the parties may call for re-calibration of any instrument during the run of the tests.

7. Preliminary test

Before the ordinary testing is started, there should be made a pre-test covering a small number of points, representative for the main test. The purpose of such a test is to give the testing staff an opportunity to check the correct functioning of the complete installation in accordance with the requirements of Chapter IV, and, which is perhaps even more important, to obtain a basis for the agreement on measuring inaccuracy.

8. Records

Complete records, giving besides all readings on turbine instrument scales, etc., from the main tests, full details on the results of inspection, calibration and preliminary testing, shall be produced in a sufficient number of copies. After being approved and signed by the parties, the records shall be kept in one full set by each party.

9. Repetition of tests

If any of the parties for clearly explained and valid reasons is dissatisfied with the test arrangement or the results obtained, he shall have the right to refuse signing the records and to demand a new test.

Another reason for repetition of the test, without changing the guarantees, would be that during the manufacture of the prototype machine or upon installation of the same, there have been stated such deviations from the conditions of the first model test that the deviations from the assumption of geometric similarity, upon which the test was based, exceed the permissible deviations of Sub-clause IV.2.4.

10. Cost of repeated test

It is recommended that the responsibility for the cost of repeated calibrations (Clause V.6) or repeated tests (Clause V.9) be clearly stated in the contract documents.

CHAPTER VI — COMPUTATION OF RESULTS

1. Calculation of model performance

1.1 *General*

Using the methods of measurement described in Part 2, the test data shall provide for each test point, the quantity of water (Q_p) the head (H_p), the turbine output (P_p) and the speed (n_p) of the prototype turbine given by the following formulae:

$$1)\quad Q_p = Q_m \left(\frac{H_p}{H_m}\right)^{1/2} \left(\frac{D_p}{D_m}\right)^2$$

$$2)\quad P_p = P_m \left(\frac{H_p}{H_m}\right)^{3/2} \left(\frac{D_p}{D_m}\right)^2$$

$$3)\quad n_p = n_m \left(\frac{H_p}{H_m}\right)^{1/2} \left(\frac{D_m}{D_p}\right)$$

The turbine efficiency which is taken over unchanged for this conversion is:

$$\eta_p = \eta_m = \frac{P_t}{Q\ H_n} \times \frac{1}{\gamma} \quad \text{using consistent units.}$$

1.2 *Comparison to guaranteed model efficiency*

When the model efficiency is guaranteed, a table will be established in the following manner for each guaranteed head:

TABLE III

Q_p	η_p	η guaranteed

1.3 *Comparison to scaled-up model efficiency*

When the prototype hydraulic efficiency is guaranteed with an allowance for scale effect, a table will be established in the following manner for each guaranteed head:

TABLE IV

Q_p	η_m	η_p	μ guaranteed

with η_p given by:

$$\eta_p = \eta_m + \Delta\eta = \frac{P_t}{\gamma Q H_n} + \Delta\eta$$

$\Delta\eta$ being computed as explained in Clause VI.6.

1.4 *Comparison to guaranteed model output*

When output is guaranteed on the model, a table will be established in the following manner for each guaranteed head:

TABLE V

Q_p	P_p	P guaranteed

1.5 *Comparison to prototype output*

When output is guaranteed on the prototype, a field test can be made (I E C Publication 41, Field Test Code) or an output transposition formula can be agreed upon between parties before establishing the contract.

2. Inaccuracies in measurement

2.1 *General*

Every measurement is attended by unavoidable inaccuracies even when the methods, instruments and calculations employed correspond exactly with this Code. When comparing the results of the tests with the guarantee figures, these inaccuracies in measurement must be taken into account in a suitable manner. This can be done in various ways.

2.2 *Random and systematic errors*

The total inaccuracies include both random and systematic errors.

The influence of the random errors shall be reduced, using the methods set forth in Chapter V.

The systematic error depends on the method of measurement, on whether it is a primary method, or a secondary method needing calibration. The treatment of systematic error is defined in Clause VI.3.

2.3 *Measurements*

Inaccuracies relate only to the measurements themselves and do not relate to the performance of the turbine.

3. Individual errors in measurement

If there is no agreement to the contrary, the following values can be used as a guide for the calculation of a value for probable inaccuracy f_η (see Clause VI.4) from the estimated inaccuracies of each individual item measured.

3.1 *Rate of water flow*

	Probable inaccuracy f_Q
3.1.1 Reservoir	± 0.3%
3.1.2 Weighing tank	± 0.3%
3.1.3 Moving screen	± 0.3%
3.1.4 Weir without end contraction calibrated *in situ*	± 0.5%
3.1.5 Weir without end contraction uncalibrated	± 1.5%
3.1.6 Standard orifices, standard nozzles, standard Venturi tubes in new conditions operating according to ISO standards	ISO
3.1.7 Standard orifices, nozzles or Venturi tubes calibrated *in situ*	± 0.5%

3.2 *Free level*

Measurement of free water level differences *h* (in m)
(Not for weir measurement).

	Probable inaccuracy f_h
3.2.1 With pointed hook, float gauge, fixed scales	$\frac{1}{h}$ %

3.3 *Pressure*

	Probable inaccuracy f_p
3.3.1 Weight manometer	± 0.1%
3.3.2 Mercury column manometer (*h* in m)	$\pm \frac{0.1}{h}$ %
3.3.3 Spring pressure gauge, if calibrated at site	± 0.5%

3.4 *Output*

By measurement of torque and speed.

3.4.1 Torque — *Probable inaccuracy* f_T ± 0.2%

3.4.2 Speed — *Probable inaccuracy* f_n ± 0.1%

3.5 *Time*

The time measurement is also subject to systematic and random errors which shall be investigated. In most cases, systematic errors are negligible.

3.6 *Head*

This inaccuracy f_H can be computed with a fair approximation from the inaccuracy f_h of the head *h*, from the inaccuracy f_p of the pressure *p*, and from the specific weight γ by:

$$f_H = \pm \frac{(f_h \cdot h) + (f_p \cdot p/\gamma)}{h + p/\gamma}$$

4. Turbine efficiency

The inaccuracy f_η of the turbine efficiency determination is computed from the estimated individual inaccuracies by:

$$f_\eta = \pm \sqrt{f_Q^2 + f_H^2 + f_T^2 + f_n^2}$$

5. Random errors in measurement

The probable random error of the measurement will be determined in the normal statistical manner and enough observations shall be taken to reducc the probable error to within ± 0.1 %.

6. Application of scale formula

In these cases where the prototype efficiency is to be based on model tests scaled-up by some agreed formula, prototype efficiencies should be obtained by adding $\Delta\eta$ as calculated below to the model efficiencies of Table IV.

The increase in efficiencies $\Delta\eta$ is obtained from the following equation:

$$\Delta\eta = (1 - \eta_m) \left(1 - \frac{1 - \eta_p}{1 - \eta_m}\right)$$

where $\frac{1 - \eta_p}{1 - \eta_m}$ is given by the agreed scale formula applied according to the corresponding rules also agreed upon.

If no formula is agreed beforehand, the following shall be used ($\Delta\eta$ being computed for each individual guaranteed point):

For Kaplan and propeller turbines, the Hutton formula:

$$\frac{1 - \eta_p}{1 - \eta_m} = 0.3 + 0.7 \cdot \left[\frac{D_m \ \nu_p}{D_p \ \nu_m} \left(\frac{H_m}{H_p}\right)^{1/2}\right]^{1/5}$$

For Francis turbines, the Moody formula, which, for convenience is assumed to cover hydraulic efficiencies, as follows:

$$\frac{1 - \eta_p}{1 - \eta_m} = \left(\frac{D_m}{D_p}\right)^{1/5}$$

For impulse turbines it is assumed that $\eta_p = \eta_m$.

7. Runaway speed

The runaway speed of the prototype will be calculated from the runaway model test results by taking into account the power losses of the thrust and guide bearings at runaway speed and the windage losses of the generator.

It is therefore necessary that the measurement of runaway speed be carried out so as to provide the torque-speed relationship for the smallest values of the model-runner torque.

CHAPTER VII — FINAL REPORT

1. Preparation of report

The final report shall be prepared in draft form and submitted to the purchaser and supplier of the turbines, to obtain approval of both parties as to the details of calculation and the presentation of results. Any difference in viewpoint shall be resolved by both parties, with each having equal rights in determining the final form of the report.

2. Content

The final report shall contain, but not necessarily in this order, the following:

2.1 Object of test.

2.2 Record of any preliminary agreements pertinent to the test.

2.3 Personnel taking part in the test.

2.4 Description of model turbine.

2.5 Description of equipment and calibrations used for power, head, flow and speed measurements.

2.6 Procedure in making the tests.

2.7 Sample calculation for at least one run in detail from original data to final result.

2.8 If requested, daily log of the events of the test.

2.9 Efficiency step-up formula used, if any, and procedure for calculation.

2.10 Tabulation of results of calculations.

2.11 Statements as to inaccuracy of each class of measurement and inaccuracy of data based on combined measurements. Unfavourable influences during the tests shall be recorded.

2.12 Discussion of the test results; comparison with the guaranteed data, and technical conclusions.

Part 2 — Methods of measurement

CHAPTER VIII — METHODS OF DISCHARGE MEASUREMENT

The measuring methods for discharge through a model turbine can be grouped in two classes:

a) *Primary methods* (measurement of length, time and weight) which comprise gravimetric, volumetric methods and the Andersson screen.

b) *Secondary methods*, which comprise:

Determination of velocity by current-meters or Pitot tubes on one hand, weirs and differential meters such as Venturis, orifice plates, etc., on the other. While velocity distribution is seldom used for model tests, piezometric methods (weirs and differential meters) are particularly convenient to use, for they allow measurements to be made in a relatively short time. The determination of discharge from their indications nevertheless requires a calibration which can only be carried out by one of the *a)* methods, unless those meters are installed according to standards, the accuracy of which can be considered as satisfactory. Moreover, in order to guard against any accidental malfunctioning of these instruments, it may be recommended to use simultaneously several measuring instruments in series, as stated in Sub-clause IV.1.4.

1. Discharge measurements by volumetric measurement

The accuracy of this method is a direct function of the degree of exactness with which the capacity of the reservoir is known. The greatest care must be taken in establishing this capacity, which shall be regularly checked.

The most precise method of calibration consists in weighing the water contained in the reservoir. This method is applicable directly in the case of small movable reservoirs.

When using large fixed reservoirs, a totalizing method can be used.

In this case, the main reservoir is calibrated by means of an auxiliary reservoir that is of the form of a calibrated pipe so that its level of filling determines with precision the volume utilized.

One must take into account the water that adheres to the walls of the calibrating reservoir when empty, the volume of this residual water varies with the time of draining out and a little with the temperature (due to the viscosity and the surface tension).

One may, on the other hand, determine the volume by measuring the geometric dimensions. It is necessary to make a very large number of measurements to take account of all the irregularities in the walls.

Whenever possible, several methods shall be used to measure the capacity of the reservoir; in any case a curve or a table of volume versus water level shall be established.

After each measurement, the magnitude of the errors shall be determined.

It is also necessary to provide against certain errors such as the absorption of water by coatings or linings, deformation of the walls, leakage, and other causes, particularly rain, evaporation, etc.

Every effort should be made to proportion the reservoirs with respect to the flows to be measured so that errors of time and level will be kept as small as possible.

The reservoirs, whether fixed or movable, shall be checked by filling, especial care being taken to check any distortion which may have arisen during construction or transportation. Reservoirs for these purposes should be constructed of the proper materials; in particular the reservoirs can be of steel plate reinforced on the sides.

1.1 *Installation*

Reservoirs are generally of cylindrical form with the circular section on the vertical axis and are of steel or reinforced concrete with a watertight lining.

If local conditions require the installation in an excavated area, it is desirable to provide an empty space around the exterior walls to avoid any deformation due to earth pressure.

The volume used for measurement should normally correspond to a filling time of at least 100 seconds. The ratio of height-to diameter should preferably be relatively large to provide good accuracy relative to the filling volume on one part and to limit the oscillations in the reservoir on the other.

1.2 *Drain valve*

Draining will be accomplished by a valve at the bottom, the tightness of which can be checked, or preferably by a siphon supplied with an effective vacuum breaker.

1.3 *Measurement of height of water surface*

The height of the water level can be measured by a point gauge or a " float gauge "; but for large discharges on account of the relatively great variation in the water surface, these devices should preferably be installed in a stilling chamber having a transparent side and furnished with a fixed graduated scale.

Care shall be taken to eliminate errors due to temperature differences between the reservoir and the stilling chamber.

1.4 *Method of inflow*

The means of admitting water to the measuring tank must allow the diversion of the flow from the test installation either from the interior or exterior of the reservoirs in as short a time as possible. It is desirable to provide means to keep the error, due to the non-instantaneous movement of this device, to at most 20 to 50% of the time necessary for its full travel. This inflow device can consist of a movable channel or a deflector. Collecting time less than 100 seconds can be used by agreement. In any case, for large flows which can result in very large forces, a deflector can be used with a relatively slow movement (1 to 2 seconds) providing its discharge is such that the variation of flow as a function of the stroke of the deflector is constant and should preferably be linear and be completely controllable.

For large size reservoirs, the inflow must provide means for reducing the entrainment of air into the reservoir (the inflow may be guided to the lowest part of the reservoir through a centrifugal de-aerating device). The water level measurement shall not be taken until the water is free from bubbles.

1.5 *Method of operation*

The reservoir is first filled just to the level of initial measurement.

After having reached this level, the test installation having already been in steady operation, the inflow device is abruptly moved to discharge into the reservoir. As soon as the reservoir is filled to the desired point, the reverse movement of the inflow device acts to direct the water outside of the reservoir.

It is then necessary to wait until the eddies die out after which the reading of the new level can be taken. The movement of the inflow device can be recorded at the same time as the movement of a pendulum with an electric contact.

If the incoming flow is very smooth, it may be possible to record the increase in level during the filling time. This recording of the level will permit the observation of the variation in water surface before and after the filling operation and thus take account of the influence of air entrainment in the water that may be released very slowly.

1.6 *Corrections*

Calibrations of the reservoir is made by a volumetric method or by weighing various increments of inflow and, if possible, by doing this for different water temperatures.

Any flow measurement using reservoirs must take account of the water temperature, the evaporation losses and the water adhering to the walls of the reservoir. The storing of water in the reservoir will generally reduce appreciably the volume in the supply tank of the testing flume. As a result the level in the latter will drop during the filling of the measuring reservoir and cause a variation in discharge in the test flume. This can be accounted for by recording the flow during the course of the test or by adjusting the regulating devices of the test flume in a manner that will compensate for changes in the water level or preferably by installing between the supply tank and the suction of the pump a small reservoir with a regulating valve to control automatically the level of the water entering the pump to keep this constant independent of that in the supply tank.

1.7 *Use of two calibrated reservoirs*

To reduce the error due to operating time of the flow switching or if it is desired to measure the discharge over a long period, two similar reservoirs having approximately the same capacity can be used, measurements being done on one while the other is filling. The time error is thus reduced and the total error depends largely on the accuracy of measuring the volume.

The two reservoirs are connected at the top by a sharp angle splitter weir. Check valves or quick-acting valves are located at the bottom. A movable channel diverts the water of the installation towards one or the other of these reservoirs.

The measurements are made in the following manner. At the start of the run, the switching device diverts the water towards one of the empty reservoirs whose shut-off valves is closed. The filling continues until the water flows into the second reservoir by means of the weir. The flow is then diverted into the second reservoir. While filling the latter (the stabilizing time of the water level can be reduced by reducing the cross-section of the reservoirs at the top), the water level of the first reservoir is allowed to become stable and is then emptied rapidly. At the end of the run while the filling reservoir is not yet full, the flow is diverted towards the empty or emptying reservoir. The total injected volume is thus equal to the product of the number of total fillings by the volume of the reservoirs plus the volume, at the end of the run, of the partially filled reservoir.

2. Gravimetric method

An alternative to the volumetric method is to collect the flow for a known time and weigh it. This has the advantage of being more direct than the volumetric method which itself is dependent upon calibrating the collecting vessel against known weights of water. It is thus much easier to maintain high accuracy with the gravimetric method but its use is normally restricted to flow rates below about 1 m^3/s because of the size of apparatus required.

2.1 *Collecting tank*

The tank should be large enough to allow a reasonable collecting time, consistent with the accuracy required and that of the timing apparatus used. It can be of any shape and should preferably be of light construction. Suitable precautions should be taken to avoid water splashing out of the tank and internal baffles should be installed to damp out oscillations.

The tank can be either suspended from the weighing scales or mounted on top. In the latter case it is essential to ensure that no water finds its way into the weighing mechanisms.

In order to prevent shock loads being imposed on the weighing scales, the tank should be clamped during the time that the water is filling it.

When the tank is installed above the sump, a watertight drain valve may be used or a siphon device, both of which must be checked for leakage. When the tank is at the same level as the sump, a pump must be used to empty the tank. This can either be of the submersible type mounted inside the tank, or self-priming type mounted outside. In either case special precautions must be taken to ensure that there is no direct connection by electrical leads or piping between the collecting tank which is being weighed and the fixed parts of the installation. This can be achieved by means of flexible electrical leads and movable pipe connections.

2.2 *Weighing device*

The weighing device should be of an approved type, having suitable sensitivity and accuracy. It should be checked throughout the whole of the range of the device by means of precision weights, due allowance being made for air buoyancy. The device should be regularly serviced by experts and calibrated in the position in which it is used for tests. If insufficient weights are available to cover the full range of the device, an incremental method may be used by mutual agreement whereby water is exchanged alternately for precision weights so as to fill the tank in steps, using the weights to check the intervals accurately.

2.3 *Switching and timing*

The filling is made as indicated in Sub-clause VIII.1.4.

2.4 *Method of operation*

The recommended method of operation is to take an initial weight reading W_1 of the collecting tank plus that of the water remaining in it, switch the water into the tank and collect the flow for an accurately-measured time interval T; measure the final weight W_2.

The volumetric flow is then:

$$\frac{1}{\gamma} \cdot \frac{W_2 - W_1}{T}$$

where γ is the specific weight given in Table I (Chapter II).

2.5 *Precautions*

Adequate corrections must be made for water temperature which should be measured regularly throughout the tests (a 10 °C change will alter the specific weight by 0.2%).

3. Andersson's movable screen

3.1 *Basic principle*

This method resembles the volumetric method due to the fact that the volume of water displaced in a canal during a set period of time is measured; this volume is limited by the walls of the canal and the initial and final positions of the screen resulting from its travel, that is, points between which the screen has passed at times T_1 and T_2, the difference $T_2 - T_1$ constituting the "travel time".

If we designate:

L = the length of the baseline between the two measuring points

A = the wetted cross-section of the canal

$t = T_2 - T_1$ the total travel time between the two measuring points

Q = the discharge to be measured

$$Q = \frac{L \times A}{t}$$

It should be noted that the cross-section is often rectangular, and in this case is equal to the product of the water height h and the width l of the measuring canal.

3.2 *Installations*

The measuring canal shall comprise a straight horizontal section, generally rectangular, and very precisely calibrated over its entire length *; this length shall be sufficient to ensure uniform motion of the screen over the whole section between the two measuring points.

The screen, more often supported by a carriage rolling on rails ** installed along the length of the rectangular part of the canal, is often constructed of a light rigid material mounted on a lightly built frame.

The carriage and screen assembly shall be as light as possible and the friction shall be reduced to a minimum such that the screen velocity will rapidly equal the mean velocity.

Actually, it is essential that the introduction of the screen into the measurement channel shall disturb the flow as little as possible and not set up ripples or waves capable of entailing serious errors. This also applies, but to a lesser extent, to the screen exit, when the discharge measurement should be made by means of an apparatus calibrated under steady flow.

The clearance between the side of the screen and the wall of the canal must be very small, from 2 to 5 mm for a screen of 1 m^2 surface area, without, in trying to diminish the clearance, risking contact with the walls.

3.3 *Measurements of the travel velocity of the screen*

The measurement of the screen velocity shall be made by means of two fixed points indicating the length of the test section installed at the origin and extremity of the measuring section. These points can be electrical contacts or photo-electric cells operating an electric timer. It is desirable to place a certain number of points along the measuring section in order to check the uniform movement of the carriage. This can be done by means of contacts placed along the carriage rails, connected in parallel in an electric circuit with a recording pen capable of registering, on one band of a chronograph, the position of the screen at different points along the path.

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* It is possible to calibrate the measuring reach by a volumetric method if it is necessary to obtain high precision or if the canal is of an irregular shape.

** In certain cases, restrictions call for the use of a floating screen; in such cases care must be taken in the guiding and balancing of the screen as well as to avoid contact with the bottom of the canal.

3.4 *Determination of the canal cross-section*

The cross-sectional area of the canal corresponding to the water level at the side can be determined by a geometric or volumetric measurement. The level should be checked during the course of measurement by means of measuring wells placed along the walls of the measuring section.

3.5 *Controls during the run*

The precautions taken to ensure uniform velocity of the screen in the measuring section are made in order to equalize the velocity of the water and that of the screen. This can be checked by the measurement of the water level at the front and rear of the screen by means of point gauges installed in measuring wells. It is assumed that the screen is travelling at the water velocity if a negligible level difference is observed (0.5 mm) between the front and rear of the screen.

It has been observed that the proper functioning of the screen led ordinarily to slight disturbances in front and rear on the bottom of the canal and in the front and rear of the walls, especially in the vicinity of the free surface. This observation can possibly constitute, along with the negligible variation of the water height at the moment of the passage of the screen, a valuable criterion on the proper functioning of this system.

4. Weirs

The use of weirs is possible for all test laboratories having a free water surface. This device possesses a great sensivity and by means of having a free water surface results in great stability. On the other hand, it is very sensitive to any changes in the distribution of velocity of approach and to the physical state of the upstream face of the weir plate. For these reasons it is desirable to provide in all such installations the means to calibrate this device. Nevertheless, for a rectangular sharp-crested weir aerated and without end contraction, it may be agreed to use the S.I.A. and Kindsvater formulae and corresponding installations as standardized by ISO. If the accuracy of these standards is not sufficient, a calibration must be made.

All other types of weirs can only be used as a secondary method of measurement against some other method.

5. Differential meters

Differential meters, such as Venturi meters, orifices and nozzles, are particularly adapted to small-size installations or those operating on closed circuit without a free water surface. The piping arrangement of the meter shall ensure a smooth, non-rotating flow approach to the meter over the whole range of dischatge. Straightening vanes, honeycombs, or similar devices, should be placed at suitable distances upstream of the meter.

Discharge measurement by orifices and nozzles have been standardised by ISO/TC 30. These standards should be used whenever possible if their accuracy is regarded as satisfactory.

When the standard installation conditions cannot be fulfilled, these meters will be calibrated under their measuring conditions.

Several pairs of independent pressure connections should be used in order to detect easily any evidence of accidental error in the measurement due to conditions of the connection to the apparatus or to the pressure connections.

6. Others methods

Other methods may be used, by agreement, provided they can be reliably calibrated.

CHAPTER IX — METHODS OF HEAD MEASUREMENT

1. General conditions

Readings of turbine head shall only be taken when conditions are steady (see general remarks in Sub-clause IV.1.3 on limits of steadiness). For each load point, a minimum of five readings shall be taken at uniform intervals; the actual number of readings depending on the magnitude and frequency of variations (see Clause VI.5).

2. Free water level

At the section chosen for measuring free water levels, the flow should be steady and as free as possible from asymmetry and other disturbance. To ensure such uniform conditions, it may be necessary to use separately or together, flow straighteners, baffles and screens. Such smoothing devices are only permissible when they do not disturb the measuring section or the operation of the turbine. In order to make allowance for the kinetic energy head of the water, the section chosen must have a clearly-defined and easily-measured cross-sectional area. Measurements of water level must be obtained where possible from at least two points, one at each side of the measuring section, and the readings averaged to obtain true level. (See Clause IX.6, Damping devices).

Where the water surface is accessible and sufficiently calm, the tailwater level should be determined in the section of the draft tube outlet. If this is impossible, either a closed draft-tube section immediately upstream, or an open section in the tailrace downstream of the draft-tube outlet may be used. Due care should be taken in the computation of the total head to allow for any pressure recovery at outlet from the draft tube.

If the free water surface is not accessible or not sufficiently calm, stilling wells may be provided, preferably one at each side of the measuring section. The connecting channels or tubes must be constructed at right angles to the wall of the measuring section and shall be covered with smooth, perforated plates, flush with the wall (see Figure 6). The size of such perforations shall be about 3 mm bore and their total cross-sectional area, and also that of the interconnecting passage, shall not be less than 5 % of the cross-sectional area of the stilling well.

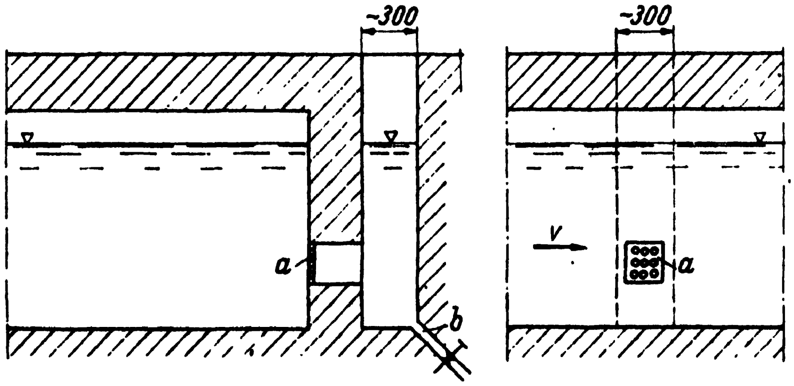

Fig. 6. — Measuring well.

a) Perforated plate
b) Flushing valve

3. Measuring apparatus for free water level

3.1 *Point and hook gauges*

Point or hook gauges (see Figure 7) may be used to determine the level of calm water either directly or in stilling wells. In place of the normal visual indication of contact with the water, electrical, optical and other indicators may be used provided they are calibrated against the direct visual method.

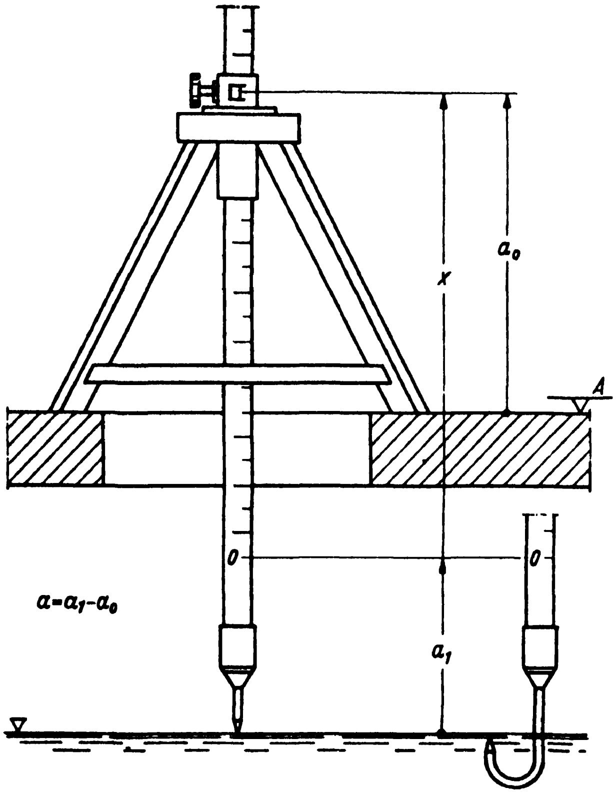

FIG. 7. — Point and hook gauges.
A) Fixed point

3.2 *Float gauges*

Float gauges, properly calibrated and in good working order, may be used and are convenient where the water level is variable. The float shall be at least 150 mm in diameter and shall return to within 1 mm of the original reading when manually deflected. The corresponding minimum dimension of well shall be 200 mm. Metal tapes, optical and other remote-reading systems must be checked for accuracy and sensitivity.

3.3 *Liquid manometer*

Alternatively the free water level may be determined from head measurements on a liquid manometer, due allowance being made for differences in height between the pressure tapping and the manometer zero. Measurements should be made as detailed in Clause IX.4.

4. Static pressure measurement

As an alternative to measuring free water level directly, the static pressure of the water at appropriate points can be measured and the reading converted into a head. As the water temperature may vary considerably during tests on a model turbine, it is particularly important to record temperatures regularly and to allow for resulting variations in the specific weight of the water when converting from pressure to head by means of the expression $h = p/\gamma$.

The ambient atmospheric pressure during the tests should be read by means of a standard mercury-in-glass barometer.

4.1 *Choice of measuring sections*

The following should be considered when selecting a measuring section to obtain static pressure measurements:

a) There should be a minimum of disturbance in the flow; sections where the velocity pattern is seriously distorted by an elbow, valve or other upstream disturbance should be avoided.

b) The flow must be free from vortices and rotational effects likely to give errors in mean static pressure.

c) The section chosen must have an easily measurable cross-sectional area, in order to enable an allowance for the kinetic energy head to be made.

4.2 *Number and location of pressure holes*

At least four static pressure holes should be installed at each measuring section on two perpendicular diameters in the case of a circular pipe or in a symmetrical arrangement, in a rectangular section, with the holes at the mid-points of the sides. If possible, in the case of a circular section, the holes should not be sited at the highest or lowest points of the section, in order to avoid air pockets and silting, respectively (see Figure 8). They should be connected to a manometer by a manifold or similar device giving lines of equal hydraulic resistance (see Figure 9). As the level of the measuring point will be assumed to be that of the centre of area of the group, it should coincide with the centre line of the measuring section. If flow conditions are disturbed or asymmetric, more than four holes should be used. If the pressures measured individually at each of the holes differ by more than 0.2% of the turbine head from their arithmetic mean, the measurements shall be deemed invalid.

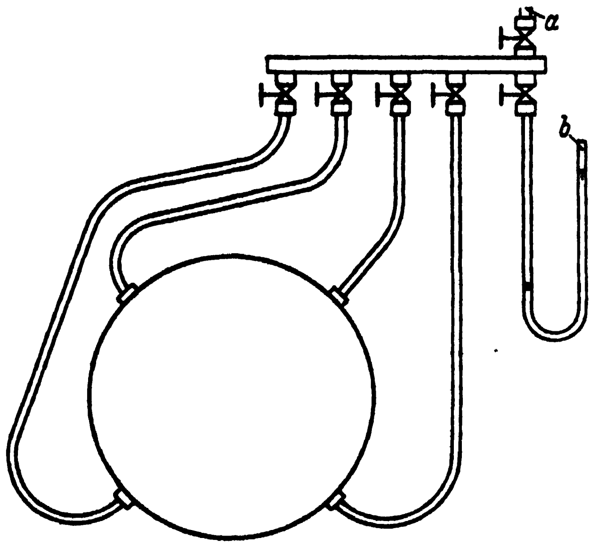

FIG. 8. — Pressure tappings connected through separate pipes to manometer.

a) Purging
b) Pressure gauge

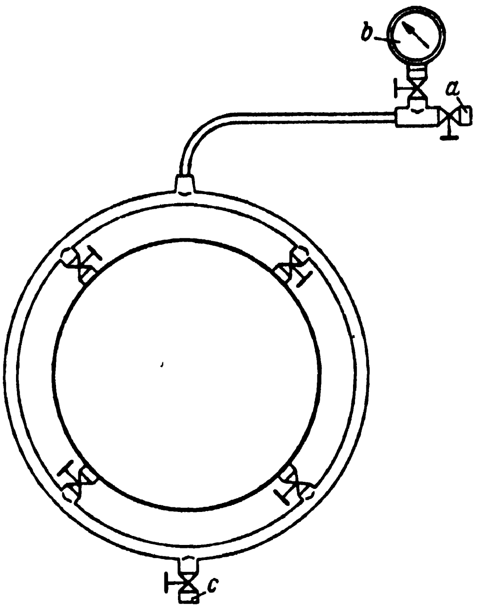

FIG. 9. — Pressure tappings connected through ring main to pressure gauge.

a) Purging
b) Pressure gauge
c) Drainage

4.3 *Static pressure holes*

The cylindrical bore *d* of the static pressure holes should be perpendicular to the wall of the conduit and 3 to 6 mm in diameter (see Figure 10). It should have a minimum length at least twice the bore of the hole. Burrs should be removed and the mouth rounded off with a radius not greater than *d*/4 (see Figure 10). The surface surrounding the pressure tapping should be smooth within at least 100 mm from the hole.

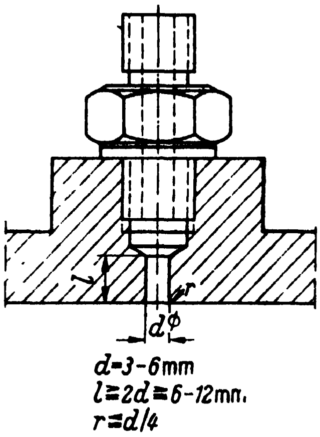

FIG. 10. — Pressure tapping.

4.4 *Pressure pipe connections*

To avoid trapping air, pipe connections should be continuously rising, without loops or sags. Transparent plastic pipes are useful for this purpose, as air pockets can easily be seen. Air release points and facilities for purging air from the system and from the manometers should be provided wherever necessary.

5. Pressure measuring instruments

5.1 *Liquid-column manometers*

Liquid-column manometers, either single or double limb, are convenient for measuring pressures up to about 5 atmospheres absolute when mercury is used as the manometer liquid. Tubing should be uniform and at least 12 mm bore for water to avoid capillarity effects, and 8 mm for mercury. Common types are:

a) U-tubes, normal or inverted (Figures 11 and 12). The heights of the liquid columns in the two legs must be read simultaneously. Whatever combination of liquids is used, the correct effective density of the differential liquid-column must be used. In the case of the inverted U-tube, if the separating fluid is compressed air, due allowance must be made for its density.

b) Single-limb manometer (Figure 13). In this case only the height of the " single-limb " need be read and the value corrected to allow for the change of level in the reservoir. The diameter of the reservoir must be at least ten times the bore of the " single-limb ".

c) Calibrated U-tube. By means of a scale, suitably calibrated, only one limb of a U-tube need to be read.

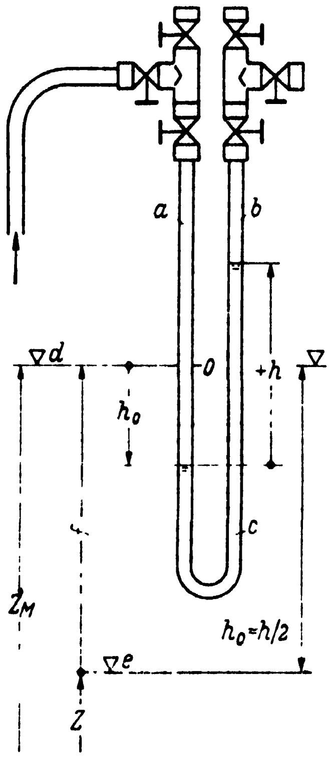

Fig. 11. — U-tube mercury differential manometer.

a) Water
b) Air
c) Mercury
d) Zero point
e) Measuring point level

$$p_g = \frac{1}{10}\left[\gamma \cdot f + \left(\gamma_{Hg} - \frac{\gamma}{2}\right) \cdot h\right] \qquad \text{(metric)}$$

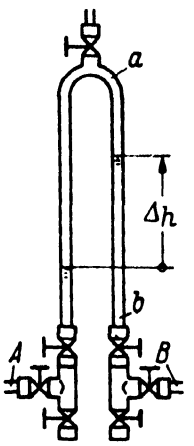

FIG. 12. — Differential manometer with inverted U-tube.

- *a)* Air (γ_a)
- *b)* Water (γ)

$$\Delta h_p = (\gamma - \gamma_a) \quad \Delta h$$

Δh_p = Difference of pressure head between the measuring section and a reference pressure

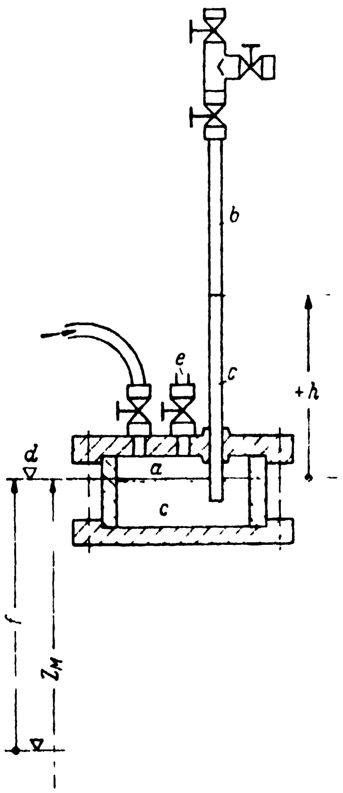

FIG. 13. — Mercury measuring pot as differential manometer.

- *a)* Water
- *b)* Air
- *c)* Mercury
- *d)* Zero point
- *e)* Purging

$$p_g = \frac{1}{10}\left[\gamma \cdot f + \gamma_{Hg} \cdot h\right] \qquad \text{(metric)}$$

5.2 *Weight manometer*

For pressures beyond the range of a mercury-column, the weight manometer or piston gauge is convenient, either in its simple or differential form (Figure 14). Generally, it is preferable to calibrate a weight manometer against a liquid column manometer to determine its effective piston diameter over as wide a pressure range as possible.

Alternatively, the effective diameter d_e of the simple piston gauge may be determined as the arithmetical mean value of the directly measured piston diameter d_p, and bore diameter d_b, and used for pressure calculation without further calibration provided, prior to the test, it is ascertained that:

$$\frac{d_b - d_p}{d_b + d_p} \leq 0.1\,\%$$

Friction between the piston and cylinder can be practically eliminated by rotating the piston at a speed not less than 30 rev/min.

Similar principles apply to the differential type of weight manometer. For measuring varying pressures, it may be convenient to use a weight manometer in series with a liquid-column manometer or a special weight manometer incorporating a liquid manometer.

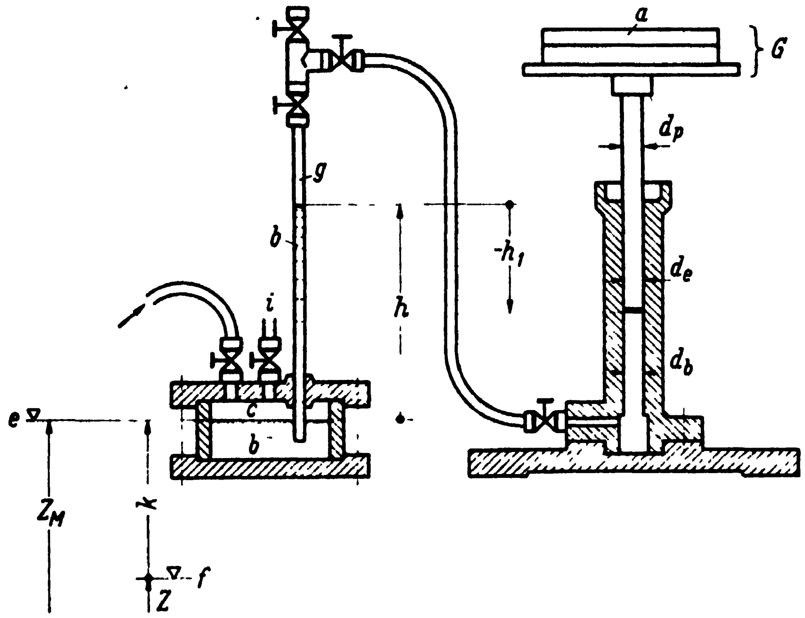

FIG. 14. — Dead-weight manometer, combined with mercury pot manometer.

a) Weights *G*
b) Mercury
c) Water
e) Zero point
f) Measuring point level
g) Oil filled
i) Purging valve

$$p_s = \frac{1}{10}(\gamma \cdot a + \gamma_{Hg} \cdot h) + p_G - \frac{1}{10} \cdot \gamma_{oil} \cdot h_1$$

wherein $$p_G = \frac{G}{\frac{\pi}{4} \cdot d_e^2}$$

(metric)

5.3 *Pressure weighbeams*

An extension of the weight manometer is the pressure weighbeam which comprises a weighbeam mounted on frictionless pivots, and bearing on one or more weight manometers or a differential type of weight manometer. The force exerted by the piston of the weight manometer is balanced by a jockey weight moving along the weighbeam (Figure 15). The operation of the weighbeam and jockey weight may be by hand or automatic by means of a suitable servo-balancing system. The sensitivity, repeatability and accuracy of such devices should be checked against a standard manometer wherever possible.

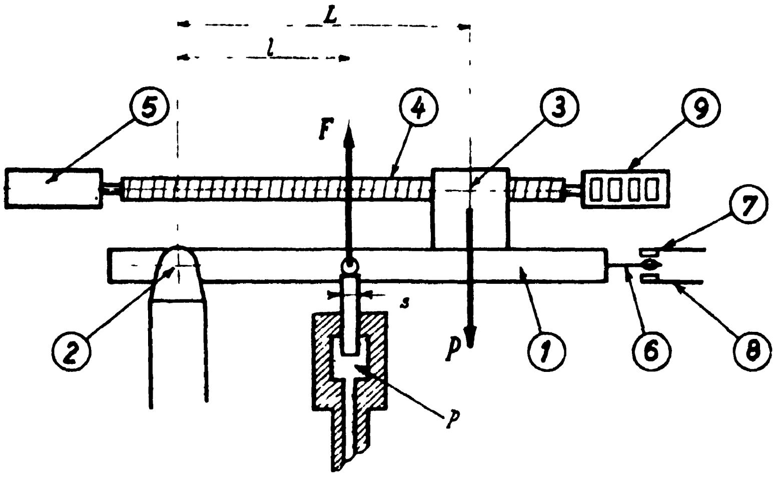

FIG. 15. — Pressure weighbeam.

1. Weighbeam
2. Frictionless pivot
3. Jockey weight *(P)*
4. Measuring screw
5. Servo motor
6. 7. 8. Electric contacts

9. Counter

$$p = \frac{P}{s\,l} \cdot L$$

s Section of the piston
p Pressure to be measured
$F = ps$ Force on the weighbeam

5.4 *Spring-pressure gauges*

This type of gauge uses the mechanical deflection of a loop of tube, plain or spiral to indicate pressure. It may be used by mutual agreement, provided the gauge is of the highest precision, it is used from 60 to 100% of its full scale reading, and it is suitably calibrated before and after the tests.

6. Damping devices

When the pressure is pulsating, it may be difficult to obtain a correct manometer reading. In order to improve such conditions, a suitable damping device may be installed, provided the flow through it is laminar and equal in resistance in both directions, thus ensuring a linear viscous resistance. This may be secured by using a capillary tube or a specially designed valve.

Wherever possible, however, pulsations should be eradicated at source and all measurements made under steady conditions.

7. Checking of manometers

All manometers should be checked over the whole of the measuring range prior to the tests, against calibrated primary or secondary instruments of a higher order of accuracy, such as precision liquid column manometer or weight manometers. Any differences in local water temperature, density and local ambient atmospheric pressure should be allowed for.

8. Vacuum measurements

8.1 *General*

For vacuum measurements all remarks made in Clause IX.5 apply, except as noted in the following Sub-clause IX.8.2.

8.2 *Vacuum pipe connections*

The gauge pipe must be either completely filled with water or, if air is used, transparent to permit observation of water level. Such pipes, when filled with water, must be flushed frequently to remove any air coming out of solution. The pipe and cocks must be free from leaks and flexible hoses may be used only if sufficiently rigid to avoid distortion or collapse by outside pressure.

CHAPTER X — METHODS OF POWER OUTPUT MEASUREMENT

1. General

The power output from the model turbine shaft may be measured by one of the following primary methods:

1) Mechanical brake;

2) Water brake;

3) Electrical brake;

and the following secondary method provided its accuracy is proved to be acceptable to all parties:

4) Torsion dynamometer.

The use of a calibrated electrical generator to measure power output is not recommended for acceptance test purposes using laboratory models.

All the above methods involve the simultaneous measurement of net torque (T in mkg) and shaft speed (n rev/min) from which the net power output in kW from the turbine shaft may be computed from the following expression:

$$P = \frac{2\pi \ nT}{60} \ \frac{1}{102} \text{ in kW}$$

In methods 1), 2) and 3), the torque on the brake is determined by the effective force applied to the brake arm and the radius at which it is applied. In method 4), the torque must be computed by means of a previous calibration.

To obtain the true power output, due allowance must be made for parasite torque losses as related in Clause X.5.

2. Torque measurement

2.1 *Mechanical brake*

The mechanical or Prony brake (Figure 16) consists of a drum on the dynamometer shaft to which a frictional torque can be applied by means of a rope, belt, brake-shoes or some other suitable device. The torque is varied by altering the frictional resistance on the drum and balancing this by weights on the brake arm. It has the advantage that high torques can be applied at low speeds even down to zero rotational speeds. The torque so applied must be steady and the mechanical system free from oscillations. In order to dissipate the heat generated, water cooling must be applied and in such a way that it does not introduce any torque errors.

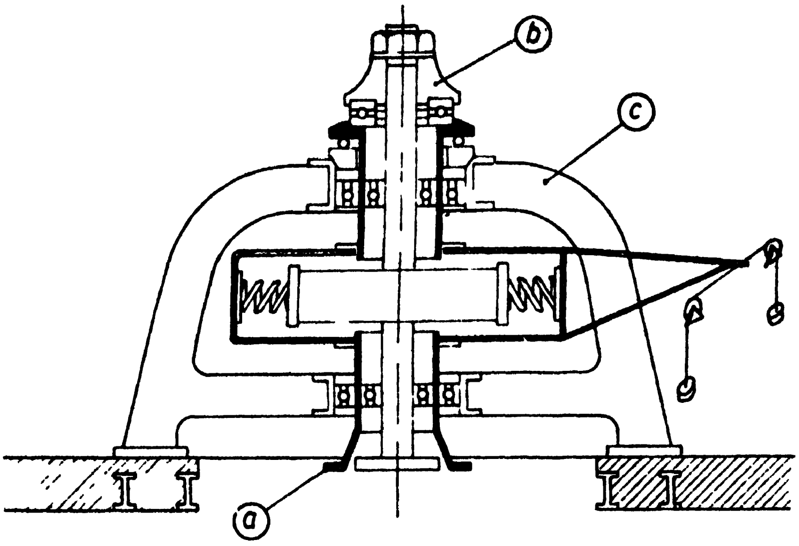

FIG. 16. — Prony brake.

a) Balancing parts
b) Rotating parts
c) Fixed parts

2.2 *Water brake*

The water or Froude brake (Figure 17) consists of a bladed disk fixed to the shaft, and rotating inside a casing filled with water or oil and able to pivot about the shaft axis. The torque is varied by altering the amount of liquid in the casing. It thus absorbs power hydrodynamically, the torque reaction being measured on the pivoting casing. It is unsuitable for use at low speeds as its power absorption varies as n^3. There are combined mechanical and water brakes which have the advantages of high torque at low speeds and flexible operation at high speeds. As the power absorbed heats the liquid, a continuous flow through the casing is required and this must be arranged so that the liquid entering and leaving the casing causes no tangential torque errors and that the flow conditions are sufficiently stable to ensure a steady applied torque. Similarly, the shaft glands retaining the liquid must either impose no sensible frictional torque or be provided with a torque measuring device.

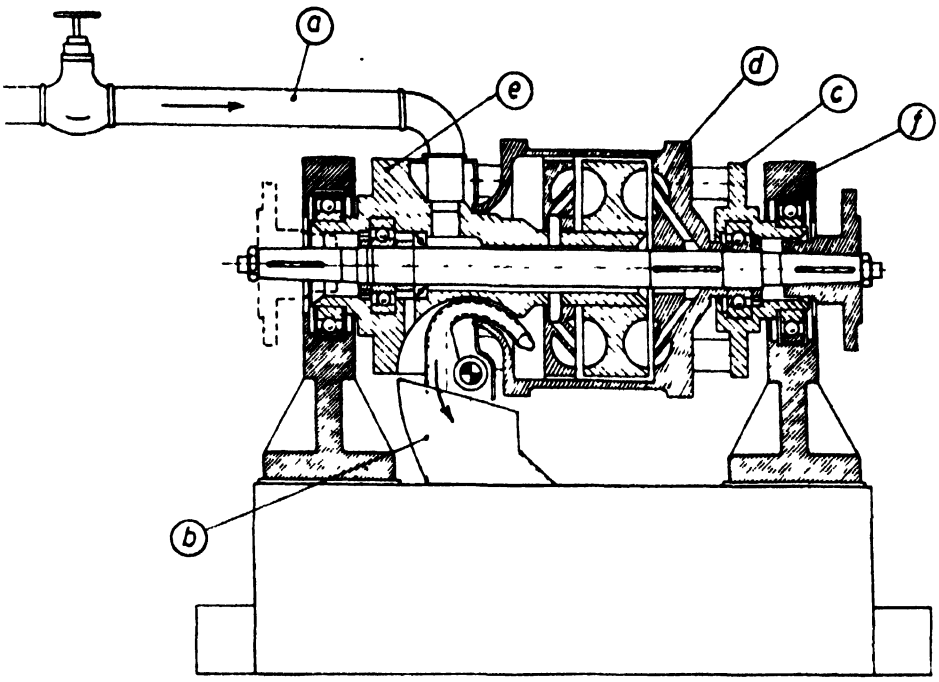

FIG. 17. — Water brake.

a)	Water inlet	*d)*	Rotating parts
b)	Water outlet	*f)*	Fixed parts
c) and *e)*	Balancing parts		

2.3 *Electrical or electro-magnetic brake*

The electrical brake (Figure 18) comprises a machine for absorbing power electrically, suitably mounted mechanically so that the torque reaction can be measured.

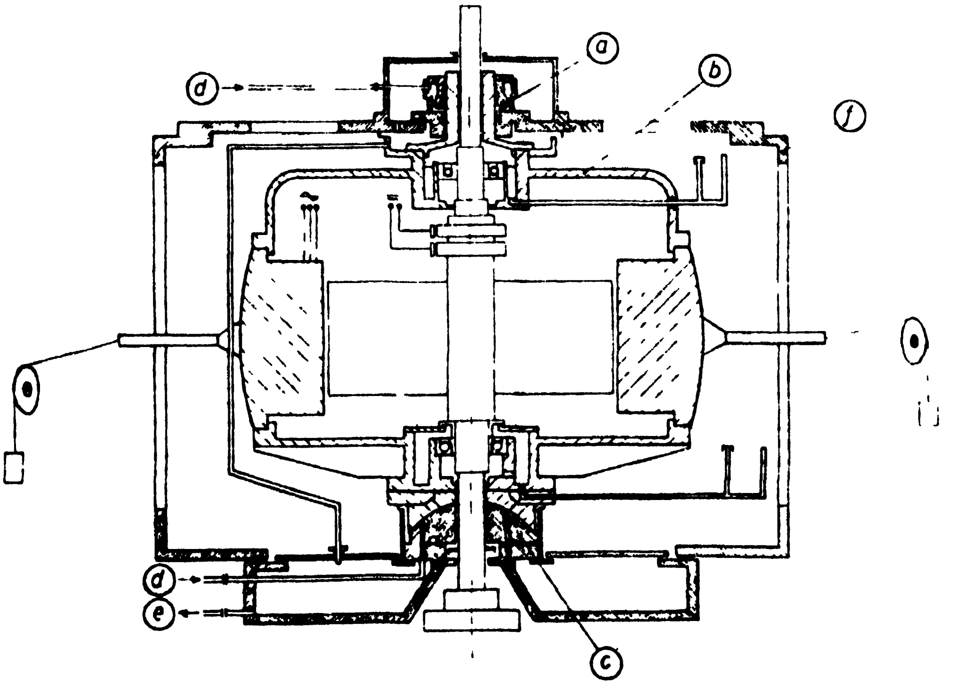

FIG. 18. — Electrical brake.

a)	**Hydrostatic bearing**	*d)*	**Oil inlet**
b)	**Balancing part**	*e)*	**Oil outlet**
c)	**Hydrostatic spherical thrust bearing**	*f)*	**Fixed parts**

2.4 *Torsion dynamometer*

The torsion dynamometer (Figure 19) comprises a length of shafting. It must be calibrated before and after the tests against some primary method.

Care must be taken to ensure that the calibration is not altered by speed or temperature.

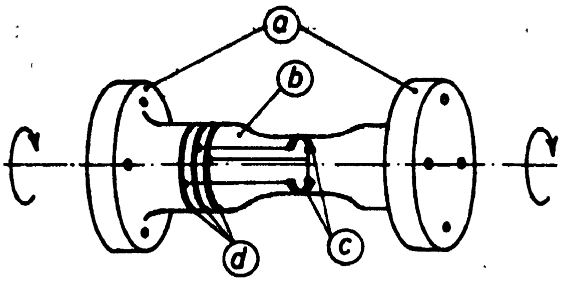

FIG 19. — Torsion dynamometer.

3. The avoidance of torque errors

The following precautions are necessary to avoid errors:

3.1 *Cooling fluid connections*

An absorption dynamometer shall be so constructed that the cooling fluid enters and leaves so as to avoid torque errors due to tangential velocity components. Similar precautions shall be taken regarding windage. Flexible pipe connections, if used, shall impose no sensible tangential restraint when under pressure. Dashpots if used shall be demonstrated to impose equal resistance to motion in either direction.

3.2 *Support bearings*

The random frictional error in the support bearing shall be demonstrated to be not more than ± 0.1% of the maximum torque over the range measured for both rotating and non-rotating conditions. To meet this requirement special low friction bearings are necessary.

Pressure-lubricated water or oil journal bearings are satisfactory, or low friction supports and also flexible metal strips, provided they are not subject to vibration or torsional oscillations. Alternatively, if conventional bearings are used of the ball or roller type, they should be " double mounted " inside another set so that the shaft bearing losses can be separately measured.

If the thrust of the model turbine is not carried on the dynamometer shaft, suitable arrangements should be made to allow for bearing friction.

3.3 *Electrical leads*

Electrical connections to the dynamometer shall impose no sensible tangential restraint. Braided flexible copper leads or mercury pots are suitable for this purpose.

3.4 *Calibration*

The effective radius-arm of the dynamometer shall be measured within an error not exceeding ± 0.05%. The error in the force-measuring system shall not exceed ± 0.1% of the reading. It shall be checked against certified weights in the directions of both increasing and decreasing load. In the case of a vertical shaft machine, metal tapes and frictionless pulleys must be used for applying the torque. Due allowance should be made for local variations in the value of " *g* " from that where the weights were certified.

Before and after the tests, the dynamometer and linkage shall be carefully checked and any unbalance determined.

4. Measurements

It is essential during a test to keep the mean speed steady to within ± 0.25%. It is also necessary to read mean speed accurately and an error within ± 0.1% should be aimed at. The following methods of rotational speed measurement may be convenient to meet this requirement:

1) Mechanically-operated revolution counter and automatically-operated stop watches or chronograph. Hand-operated stop watches can only be used if timing period is sufficiently long to maintain suitable accuracy.
2) Electrical frequency meter connected to positively driven generator.
3) Electric high-precision tachometer comprising stable permanent magnet direct current generator, driven from the turbine, and a high-grade voltmeter.
4) Electric pulse generator and electronic pulse counter and time base.

In all cases the instruments must be carefully calibrated before the tests, and demonstrated to give an accuracy of speed measurement within ± 0.1%. If cyclical speed changes are causing corresponding torque fluctuations, the mean speed and torque must be determined. If such fluctuations are acceptable, the mean of at least five readings taken at equal time intervals is necessary for torque, and for speed either the mean of five instantaneous readings, or the mean integrated speed over the period in question.

5. Losses

In order to determine the hydraulic efficiency of the turbine runner, the mechanical losses occurring between the runner and the output shaft of the model turbine must be allowed for. Such mechanical losses may, for instance, be caused by friction in the guide bearings, thrust bearings, and in the gland between the turbine shaft and the top cover of the turbine casing. As these losses are different on the model and full-scale machines and as they do not scale up in the same way as the hydraulic losses, they should be allowed for separately from the latter. The number of corrections to be made for losses will depend on the mechanical design of the model turbine and dynamometer.

CHAPTER XI: CAVITATION TESTS

INTRODUCTION

To be truly complete and representative, an acceptance model test should include a cavitation model test with the same or a similar model turbine. The purpose of this chapter is to provide suitable recommendations for such a test, based on well established theory and practice.

Principles and methods, which are still subject to research or not yet generally accepted, have been omitted or have been dealt with in a general way, avoiding too strict or formal statements.

1. Object and scope

1.1 The object of this chapter is:

- — to lay down the principles enabling guarantees to be given relating to the influence of cavitation on the performance characteristics and essentially on efficiency (Sub-clause III.2.2.1) of hydraulic turbines under specified running conditions. The checking of such guarantees shall be possible by means of model tests;
- — to describe the methods and procedures of cavitation model tests;
- — to define the methods of interpretation for cavitation model tests and the procedure for their final comparison with guarantees.

1.2 This chapter applies generally to all hydraulic turbines of the reaction type on which cavitation model tests are to be carried out.

1.3 Whilst primarily the scope of cavitation tests here described will be the verification of certain performance guarantees, it is recommended that the same principles and methods be applied for comparative tests and research tests.

1.4 Problems of behaviour and stability even when these are the result of cavitation effects are excluded from this chapter. They cannot in effect, be treated validly with the conditions of similitude taken into consideration in this chapter.

2. Guarantees for the influence of cavitation

2.1 *General*

In cases where the efficiency acceptance tests are made on a model, it is necessary to check the influence of cavitation on the model efficiencies as obtained by tests performed in accordance with the previous chapters. It is necessary to state clearly in the contract whether model guaranteed efficiencies are given under specified hydraulic conditions with respect to prevailing water levels at site, usually expressed in the form of plant cavitation factor values (See Sub-clause XI.5.1.1) or for sufficiently high cavitation factor values to exclude cavitation influence on performance. (See Sub-clause III.2.2.1)

There is not yet a commonly accepted theory for the transposition of cavitation model test results to prototype conditions ; therefore, guarantees applicable to cavitation model tests must be given for a model turbine of a given size to be treated under a head within a given head range.

2.2 *Guarantees concerning alteration of efficiency*

A guarantee is generally given concerning model efficiency under hydraulic conditions corresponding to water levels at site.

2.3 *Guarantees concerning runaway speed and/or discharge*

A separate guarantee for runaway speed and/or discharge may be given. As cavitation very often has a decisive influence on runaway characteristics, the guarantee should refer to a given range of cavitation factor σ (See Sub-clause XI.5.1.1) prevailing in the prototype installation.

The maximum runaway speed and maximum runaway discharge are the highest speed and discharge the turbine could ever reach when rotating at zero torque under the above-mentioned conditions.

In the case of adjustable blade turbines, additional guarantees may be given for the runaway speed and/or discharge for the condition in which correct combination between runner blades and guide vanes is maintained.

2.4 *Limitation of guarantees for cavitation*

Cavitation may effect the behaviour of a hydraulic turbine in several ways. It may cause noise, vibrations, material damage (pitting) and alteration of performance, as defined by changes of efficiency, output, discharge, runaway speed and runaway discharge.

When separate guarantees are made with respect to pitting, noise or vibrations, they shall always be referred to the full scale machine. Such guarantees are subject to separate checking by field investigation.

2.5 *Additional information not subject to guarantee*

In addition, the contract may stipulate, to establish during acceptance tests, a certain number of curves of efficiency against cavitation factor corresponding to predetermined operating conditions. These would generally be near the limits of the contractual range of operation for the turbine.

Depending on the type of turbine and the range of operation, these curves may have very different shapes. But for low cavitation factor, they generally show a characteristic drop in efficiency corresponding to developed cavitation. It may therefore be possible to define from these curves the characteristic values of a cavitation factor as described in Sub-clause XI.7.3.1.4, which may then be compared with the value of the plant cavitation factor.

3. **Test installations**

3.1 *General characteristics of the circuit*

The circuit shall be such that when cavitation appears in the model turbine it shall not occur elsewhere to an extent where it affects the stability or the satisfactory operation of the installation or the measurement of the model performance.

It must be ensured that cavitation and the bubbles and degassing produced by cavitation in the model do not affect the functioning of instrumentation particularly the flow measuring device.

The measuring conditions on the cavitation test rig, whether this be the same as that used for the determination of the efficiency curve or not, shall conform with the conditions specified in the other chapters of this model test code. But practical considerations (Sub-clause XI.4.1) due to low absolute pressures may require test heads higher than the minima (Sub-clause IV.2.1).

3.2 *Model dimensions*

Experience has shown that model dimensions are of great importance for cavitation tests. It is therefore essential to satisfy the minimum values required for D_s (not less than 250 mm) and R_e described in Sub-clause IV.2.1 and they should be exceeded as far as the available test installation permits.

Further recommendations governing model scale with respect to cavitation similitude are presented in Sub-clauses XI.5.1 and XI.5.2.

3.3 *Viewing conditions*

3.3.1 *Observation of the water in the circuit*

Whatever the type of circuit used, provision should be made for visual observation of the condition of the water with particular reference to the bubble content coming into the model and the cleanliness both at the inlet of the turbine and upstream of the flow measuring device.

3.3.2 *Viewing the turbine runner*

The runner chamber and/or draft tube should be designed so as to allow observation of cavitation development in so far as the dimensional instability of transparent materials does not interfere with proper clearances (Sub-clause IV.2.4), particularly with respect to the requirements of Sub-clause XI.5.3.5.

3.4 *Flow conditions in the model*

The conditions specified in Sub-clause IV.1.2 shall be fulfilled.

4. Conditions of the water

4.1 *Properties of the water*

The conditions specified in Sub-clause IV.1.1 shall be fulfilled, particularly at the inlet of the turbine and at the flow measuring device. By means of the viewing possibilities provided (Sub-clause XI. 3.3.2) a periodic check shall be made to ensure that no air leakage exists.

4.2 *Air content*

4.2.1 *General*

The total air content of the water including both entrained and dissolved air used in the test rig should be known for the test. Present experience in closed circuits indicates that the influence of air content on a cavitation acceptance test may be neglected if the total air content, at standard conditions of pressure and temperature * is not less than 2 parts in 1 000 (volume).

Inversely, in order to avoid degassing in any part of the model, the water of the circuit should not be supersaturated.

It is possible to examine this influence by repetition of the same test run under air content conditions as different as permitted by the test installation.

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* Standard conditions are defined by :
— temperature 20 °C ;
— pressure 1 bar.

In order to avoid any degassing in open or closed circuits, an increase of test head and general pressure level may be required.

4.2.2 *Air content measurement* [1], [2]

The following are examples of methods which may be used.

a) Winkler method

This method enables determining, by iodometry, the dissolved oxygen content of the water. It is accurate, but necessitates titrated solutions which are difficult to keep and it requires sampling without re-aeration of the specimen. It only yields the value of dissolved air content by a calculation.

b) Physical separation : Van Slyke method

This method has the advantage of permitting the extraction of the quantity of air contained, whether in dissolved or occluded form, by cascading the sampling under vacuum on plate-posts. The method is speedy, but necessitates working on small volume samplings.

c) Gas content recorders, used in thermal power plant

They permit a continuous recording of the total gas content, but they must be adapted to the utilization range in the laboratory where the water is usually saturated, whereas it is nearly without gas in a thermal power plant.

4.3 *Temperature*

The temperature of the circuit water shall be measured for each test point close to the model at the inlet or in the draft tube.

5. Test conditions

5.1 *Hydraulic similitude — General definitions*

5.1.1 *Cavitation factor*

In addition to the similitude requirements normally involved in the performance tests, a supplementary parameter, the cavitation factor, must be taken into account during cavitation tests.

The cavitation factor σ (Thoma's coefficient) characterizes the setting of a hydraulic turbine referred to the tailwater level. It shall be used as a basis of comparison for model and prototype cavitation conditions. The coefficient σ is a dimensionless number which expresses the difference between the absolute tailwater or outlet pressure head (referred to the elevation of a reference point on the runner), and the water vapour pressure head. This difference is expressed in relation to the net head :

$$\sigma = \frac{h_a - h'_s - h_{va}}{H_n}$$

h_{va} = vapour pressure head at the actual water temperature (see Sub-clause II.2.6.10 and TableVI, page 15).

H_n = net head (see Sub-clause II.2.6.5)

h_a = absolute pressure head in the turbine outlet section referred to any convenient level

h'_s = suction head equal to the height of the reference point of the runner above the reference level of h_a (see Figure 20, page 15.)

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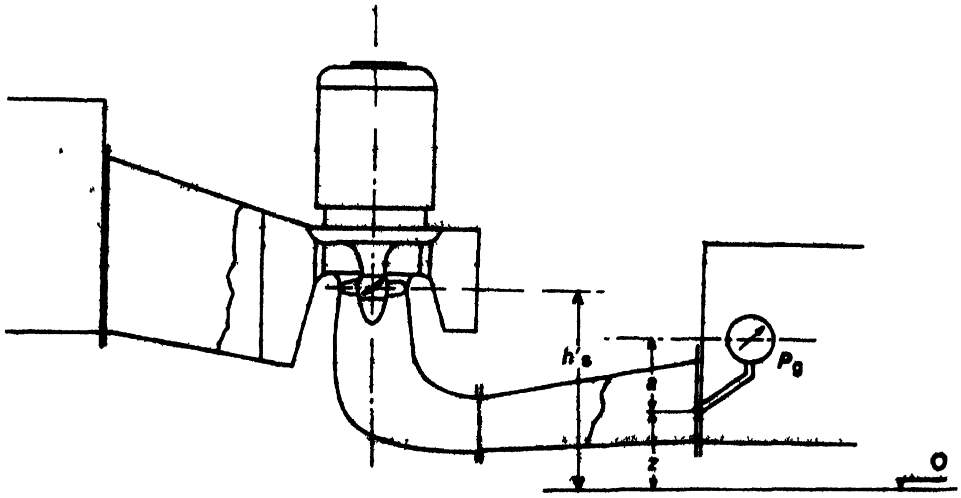
[1] P. CORMAULT : "Méthode de mesures des teneurs en gaz de l'eau et appareillages" E.D.F. — Bulletin du Centre de Récherches et d'Essais de Chatou — Supplément au No. 2, Deuxième partie — Décembre 1962.

[2] E. KANELLOPOULOS : "A critical Survey of Methods for Measuring the Total Gas Content of Water" — N.E.L. Fluids Note No. 76 — East Kilbride, Glasgow, 1959.

TABLE VI

Vapour pressure

Temperature °C	Vapour pressure			Temperature °C	Vapour pressure		
	bar	metre of water	feet of water		bar	metre of water	feet of water
0	0.006 11	0.0623	0.205	19	0.021 96	0.2239	0.736
1	0.006 56	0.0669	0.220	20	0.023 37	0.2383	0.783
2	0.007 05	0.0719	0.236	21	0.024 86	0.2535	0.833
3	0.007 57	0.0772	0.254	22	0.026 43	0.2695	0.886
4	0.008 13	0.0829	0.272	23	0.028 08	0.2863	0 941
5	0.008 72	0.0889	0.292	24	0.029 82	0.3041	0.999
6	0.009 35	0.0953	0.313	25	0.031 67	0.3229	1 061
7	0.010 01	0.1021	0.335	26	0.033 60	0.3426	1.126
8	0.010 72	0.1093	0.359	27	0.035 64	0.3634	1.195
9	0.011 47	0.1170	0.384	28	0.037 79	0.3853	1 267
10	0.012 27	0.1251	0.411	29	0.040 04	0.4083	1.342
11	0.013 12	0.1337	0.440	30	0.042 41	0.4325	1.421
12	0.014 02	0.1429	0.470	31	0.044 91	0.4579	1 505
13	0.014 97	0.1526	0.502	32	0.047 53	0.4847	1.593
14	0.015 97	0.1629	0.535	33	0.050 29	0.5128	1.685
15	0.017 04	0.1737	0.571	34	0.053 18	0.5423	1.782
16	0.018 17	0.1853	0.609	35	0.056 22	0.5733	1.884
17	0.019 36	0.1975	0.650				
18	0.020 62	0.2103	0.691				



5.1.1.1 Any cavitation factor different from σ may be used by mutual agreement. Particularly, it may be interesting, in the case of reversible pump turbines, to define a cavitation factor (C) characterizing the setting of the machine referred to the total head at the draft tube outlet. In this case, the factor (C) is a dimensionless number which expresses the difference between absolute total head at the outlet and vapour pressure head. This difference is expressed in relation to the net head.

Any method, provided correctly applied, will give equivalent results for the machine setting, but numerical values obtained may differ somewhat.

In such cases, the cavitation factor definition to be used must be agreed upon in writing between both parties before the tests.

5.1.2 *Method of measurement*

5.1.2.1 *Determination of* h_a *and* h'_s

h_a *absolute pressure head*

The measurement of pressure head is dealt with in Chapter IX. The downstream absolute pressure head to be measured will generally be below atmospheric pressure and great care must be taken to ensure that air is not drawn into the leads or measuring device (See Clause IX.8).

Note that nearly all pressure measuring devices use atmospheric pressure as a datum and allowance must therefore be made for the true value of atmospheric pressure (Sub-clause II.2.6.9) at the time of the tests.

This is true for single limb and U-tube manometers, dead weight gauges, spring gauges, pressure weighbeams, etc.

h'_s *suction head*

The measurement of h'_s is a geometric measurement and can be made with a suitable height gauge.

5.1.2.2 *Location of the reference point of runner*

Unless otherwise agreed in the contract, the reference point of the runner should be taken as defined in Figure 5, Chapter II.

5.1.3 *Froude condition*

To observe the similitude of cavitation factor for every point of the machine where it might be calculated, it would be necessary that the ratio of dimensions and the ratio of heads be the same. This is the Froude condition. It links the testing head with the dimension of the model (Sub-clause XI.5.2).

5.1.4 *Other similitude conditions*

Other similitude laws have been developed based on, for example, surface tension, thermodynamic processes associated with bubble growth, air content equilibrium and prototype head. The conclusions are diverse and the similitude criteria are contradictory and it is not possible to satisfy all criteria simultaneously.

5.1.5 It cannot be definitely stated that any of the criteria in Sub-clauses XI.5.1.3 and XI.5.1.4 is necessary and sufficient to provide cavitation similitude.

5.2 *Hydraulic similitude — Conditions to be fulfilled*

5.2.1 The additional application of the Froude condition should be considered when the vertical distance between the highest and lowest points of the full size runner blades becomes significant in relation to the plant head (approx. 0.25 H_n or more) (large low head Kaplan turbines and, particularly, tubular turbines). The cavitation acceptance test is then to be performed, unless otherwise agreed in the contract, on a large size model, installed with the axis in a position comparable with that of the prototype (e.g. horizontal or vertical) and tested under a test head close to that corresponding to the Froude similitude.

It is also advisable during model tests to observe the Froude similitude as closely as possible wherever extended cavities appear such as a vortex cavity in the draft tube at plant cavitation factor. This ensures that the flow in the model and in the prototype runner and draft tube is similar.

5.2.2 The application of the Froude condition should be waived when:

a) The vertical dimensions of the runner are, in relation to the head, much smaller than indicated in Sub-clause XI.5.2.1 (for instance, for high head Kaplan and Francis turbines): in such cases, the Froude condition is of little importance in acceptance cavitation model tests.

b) It would require operation of the rig outside its design limits or result in excessively large models and/or very low testing heads (Sub-clause XI.4.2.1).

It is generally not desirable to test the model under too low test heads because of the reduced measuring accuracy and the danger of degassing (see Sub-clause XI.4.2.1).

5.2.3 When the Froude condition should be observed but when its application is deferred for some of the reasons expressed in Sub-clause XI.5.2.2, the equality of cavitation coefficient σ cannot be attained simultaneously for all homologous levels between model and prototype.
In order to ensure in the most satisfactory way, the similitude between model and prototype cavitation influence, it is recommended to select by mutual agreement before the test, the homologous reference levels R_p and R_m in the prototype and model runner, for which the equality of coefficient σ shall be observed. When this equality is realized for the selected reference levels R_p and R_m on the prototype and on the model ($\sigma_p = \sigma_m$), it involves a difference between cavitation coefficient σ'_p and σ'_m at all other homologous levels as demonstrated by Figure 21.

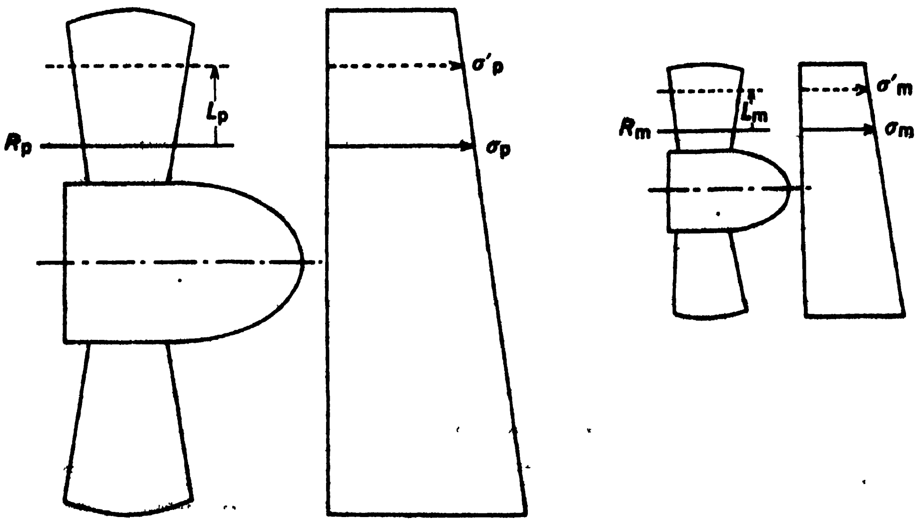


FIGURE 21

where :

m and p relate to the model and prototype

L_m = the height of the observed point on the model measured positively upwards from reference level R_m

L_p = the height of the homologous point on the prototype measured positively upwards from reference level R_p

D_m and D_p = respectively model and prototype runner diameters

H_m and H_p = respectively model testing head and prototype operating head.

According to Figure 21, page 19 :

$$\sigma'_p = \sigma_p - \frac{L_p}{H_p} \quad \text{and} \quad \sigma'_m = \sigma'_m - \frac{L_m}{H_m}$$

Also, as stated above :

$$\sigma_p = \sigma_m$$

Therefore

$$\sigma'_p - \sigma'_m = \frac{L_m}{H_m} - \frac{L_p}{H_p} = \frac{L_m}{H_m}\left(1 - \frac{H_m/H_p}{D_m/D_p}\right)$$

Note that in those cases when Froude similitude should be observed but when its application has been deferred, the test head H_m will generally be greater than the one required by the Froude condition (which means $L_m/H_m = L_p/H_p$) and $\sigma'_p - \sigma'_m$ will be negative for all homologous levels above the reference planes R_p and R_m (worse cavitation conditions for the prototype than for the model). The opposite will occur for all homologous levels below the selected reference levels.

When deciding the location of the reference level R_p, R_m, the cavitation pattern can be taken into account. It may thereby prove suitable to use a reference level deviating from those recommended in Figure 20, page 15.

5.2.4 It is unnecessary to require tests under prototype head.

5.3 *Geometric similitude — State of the model*

5.3.1 Unless otherwise stated, when the cavitation tests and the efficiency tests are conducted on different models, the model used for cavitation tests shall meet the same geometric requirements as prescribed for the model used in efficiency tests.

5.3.2 In addition to general requirements for surface conditions, great care should be given to the proper matching of joints between parts in order to avoid any local separation which may be the cause of incipient cavitation peculiar to the model.

5.3.3 Local faults on the blades or impurities adhering to the leading edge should be carefully removed so that they do not constitute weak spots at which cavitation might be started.

5.3.4 The angle of attack of the relative flow at the leading edge of a runner blade has a decisive influence on the pressure distribution and thus the resulting cavitation on the runner. It is therefore important that model turbines of the Kaplan type be tested with the correct relationship between model runner blade and guide vane settings.

5.3.5 For all types of reaction turbines, the flow in clearances between movable and fixed parts will contribute to the general cavitation picture. In particular, this is true for the seal clearances at the runner periphery. It is important therefore that the clearances adopted as described in Sub-clause XI. 3.3.2, must be maintained constant as far as possible during the period of the tests. All clearances shall be measured and recorded.

5.3.6 At the beginning of the measurements, a preliminary test shall be carried out to check that all the runner blades or vanes show a similar pattern of cavitation formation. If this is not the case, and if it cannot be corrected before the tests begin, the differences of cavitation appearances shall be recorded in the report.

6. Execution of the cavitation tests

6.1 *Testing programme*

When the testing programme is set up (See Clause V.4, Sub-clauses V.4.1 and V.4.2) arrangements for possible cavitation tests should be included. The purchaser shall have provided all the necessary data for the calculation of the plant values of the cavitation factor for each head-flow combination of the plant.

6.2 *Testing procedure*

6.2.1 *Efficiency and cavitation tests on the same model*

6.2.1.1 Model efficiency tests for the purpose of establishing whether efficiency guarantees have been met may be carried out at the plant cavitation factor values when this procedure is easily possible. This testing method only yields the performance characteristics at the plant cavitation factor

The loss caused by cavitation is assumed to be independent of Reynolds number and the usual step-up formulae are only applicable to cavitation-free performance. Therefore, when efficiency guarantees are based on model test results with allowance for scale effect, the loss caused by cavitation shall be ascertained and the step-up calculated from additional tests performed at high σ values for which efficiency is not affected by cavitation.

6.2.1.2 When efficiency and cavitation measurement within the same acceptance test are made separately, a correction on the results of efficiency tests will be subsequently applied to take into account the possible influence of plant σ.
Such measurements involve the determination of the efficiency-cavitation, output-cavitation and discharge-cavitation curves, for a series of test speeds and guide vane settings. The influence of plant σ on η, P, Q, will be deduced from these curves and applied to the measurements made at high σ values. Values of a characteristic σ as defined in Sub-clause XI.7.3.1.4 can also be derived from these curves.

6.2.2 *Efficiency and cavitation tests on different models*

When efficiency tests and cavitation tests are made on separate models, it is necessary to perform the cavitation tests, according to Sub-clause XI.6.2.1.2. The influence of plant cavitation factor on η, P, Q, will be determined from the cavitation model turbine.

If the models give different efficiency results at high σ values, the corrections on results due to cavitation will be deduced from the model used for cavitation tests and applied to the measurements made on the efficiency model turbine, which is expected to yield more accurate efficiency measurements. (See Sub-clause XI.7.2.)

6.2.3 The model turbine head and speed must be kept constant during the test. Deviations permitted in Sub-clause IV.1.3 are also applicable to cavitation tests.

6.3 *Runaway tests*

The runaway tests should be carried out with such a variation of guide vane positions (of particular importance with Kaplan turbine) and σ as to cover the guaranteed conditions. Whenever possible, the dynamometer should be arranged for driving so as to bring shaft torque down to zero. If this is not possible, the dynamometer torque must be varied during the test so as to allow extrapolation of measured speed or discharge to zero torque (See Clause VI.7.)

6.4 *Cavitation curves*

The variation of efficiency output or discharge as a function of σ may be plotted for some operating condition agreed upon in advance. It is recommended that any cavitation test be accompanied by sketches and/or photographs of cavitation development if possible at various operating conditions of the turbine and, if possible, from different angles of views. The time of exposure of photographs should be indicated.

The character of cavitation development is more exactly defined by the statement of:

— extent (the runner blades may be fitted with well distinguishable marks);
— nature (transparent or milky screen of cavitation);
— stability (constant or intermittent).

The cavitation curves may be annotated to indicate other phenomena associated with cavitation such as noise, initial bubble appearance, etc.

7. **Interpretation of tests**

7.1 The interpretation of cavitation acceptance model tests shall be made only for the purpose of a comparison with guaranteed values on performance and essentially on efficiency (Sub-clause XI.2.1) and runaway speed and discharge. No conclusions concerning the fulfilment of prototype pitting guarantees can be drawn from the influence which cavitation has on performance as revealed by the model tests.

7.2 *Inaccuracies in measurements*

7.2.1 In case tests are made at plant σ (See Sub-clause XI.6.2.1.1) the inaccuracy of efficiency f_η will be computed according to Clauses VI.2 and VI.4.

7.2.2 For tests at other σ values (Sub-clauses XI.6.2.1.2 and XI.6.2.2) cavitation tests indicate efficiency difference only, systematic errors f_η can then be disregarded and random errors reduced by performing a minimum number of tests in a normal statistical manner (Clause VI.5).

The inaccuracies f_σ on the determination of σ at which tests have been performed will be computed according to individual measurement inaccuracies on pressures heads and on each parameter involved in σ computation (See Clauses VI.2 and VI.3).

7.2.3 When different models (Sub-clause XI.6.2.2) or different test installations are used for efficiency and cavitation tests, it may happen that they give different efficiency results.

Such efficiency differences between the two models may result from several causes: scale effects on dimension or testing head, differences in accuracy between the two testing installations used, differences in testing conditions.

In any case when such differences exist, they must be examined according to each particular case and kept to a minimum in such a way that mutual agreement can be obtained on the validity of cavitation acceptance tests.

7.2.4 The test report shall include a statement on the cavitation similitude conditions specifying in particular the reference plane (or planes) in the runner used for the determination of suction head and σ and reasons for the choice. It shall also be stated in which way unavoidable discrepancies between the ideal measuring conditions have been taken into consideration (See Sub-clause XI. 5.2.3).

7.3 The interpretation of the model tests can be made by the following methods:

7.3.1 *Interpretation of efficiency tests and cavitation tests performed on the same model*

7.3.1.1 *Model tests performed at plant cavitation factor*

When measurements are made at plant σ * (See Sub-clause XI.6.2.1.1) comparison to model guaranteed efficiencies is made according to Chapter VI (See Sub-clause XI.7.2.1).

7.3.1.2 *Model test performed as individual cavitation tests*

On each cavitation curve, the efficiency under cavitation conditions is read at plant σ value. * The comparison to guaranteed values will be made according to Chapter VI and Sub-clause XI.7.2.2.

7.3.1.3 *Efficiency tests and cavitation tests performed separately*

Efficiencies measured under high cavitation factor values shall be corrected by the difference $\Delta\eta$ existing between efficiency without cavitation and efficiency at plant σ *. The comparison to guaranteed values under cavitation will be made according to Chapter VI taking in account the inaccuracy as described in Sub-clauses XI.7.2.2 and XI.7.2.3.

7.3.1.4 *Interpretation of additional tests*

When additional tests have been performed as explained in Sub-clause XI.2.5, some curves of efficiency versus σ may be drawn.

From these curves and according to their particular shape, it may be possible to determine an appropriate value of σ.

For example:

a) σ_0 the lowest value of σ for which the efficiency remains unchanged as compared to non-cavitation conditions (Figure 22, page 30.)

b) σ_1 the lowest value of σ for which a drop of 1% in efficiency is attained, compared with non-cavitation efficiency (Figure 23, page 30.)

c) σ_s "Standard sigma" the value of σ at the intersection of the constant η line (non-cavitating) with the strongly dropping straight line, along which measuring points align themselves for a high cavitation degree (Figure 24, page 30.)

d) any other characteristic σ values defined in the contract and suitable for easy interpretation on the curves:

$$\eta = f(\sigma)$$

$$P = f(\sigma)$$

7.3.2 *Interpretation of efficiency tests and cavitation tests performed on different models*

The interpretation of such tests will be made according to Sub-clauses XI.7.3.1.3 and XI.7.3.1.4.

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* This plant σ may possibly be corrected according to Sub-clause XI.5.2.3.

7.3.3 *Interpretation of cavitation runaway tests*

The runaway speed and/or discharge should be plotted in a diagram as a function of σ for each guide vane opening. In the case of adjustable blade runners, a series of diagrams will be required to cover variations in blade angle and an envelope will result. The wanted maximum runaway speed and/or maximum discharge is the highest value that can be found within the range of plant σ for which the guarantees are valid. The cavitation runaway speed and/or discharge in which correct blade/guide vane combination is maintained may also be obtained.

7.3.4 *Interpretation of informative tests*

When model efficiencies have been guaranteed for sufficiently high σ values to exclude any cavitation influence, but when a provision for cavitation model tests has been made in the programme, they will have only information value.

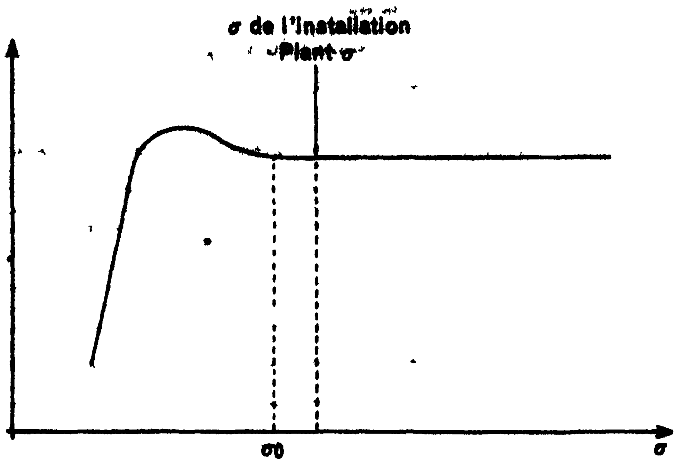

FIG. 22. — Définition de σ_0.
Definition of σ_0.

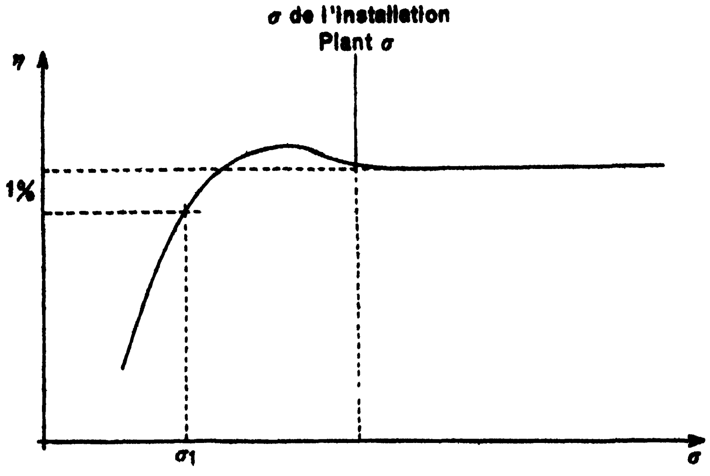

FIG. 23. — Définition de σ_1.
Definition of σ_1.

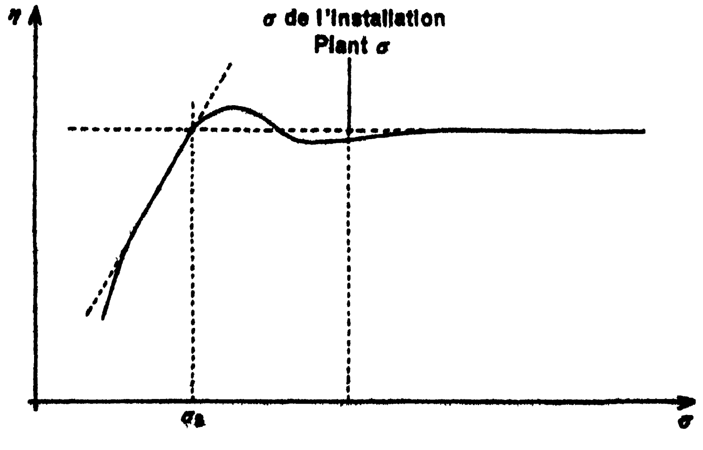

FIG. 24. — Définition de σ_s.
Definition of σ_s.

Amendment No. 1

CHAPTER IV — TEST CONDITIONS TO BE FULFILLED

Page 30

Replace Sub-clauses 2.2, 2.3 and 2.4 by the following:

2.2 *Similarity*

2.2.1 *Geometric similarity of prototype and model*

A model turbine for acceptance tests shall include the turbine itself, the draft tube and turbine casing to an upstream limit which, depending on the type of turbine, should normally exceed twice the discharge diameter of the turbine runner upstream from the centre line of the runner and be such that the inlet flow conditions are not affected by any perturbation arising from the model.

Elbows, Y-pipes, valves or a free surface upstream are not normally included in the model turbine for acceptance tests even if they are likely to affect performance.

Upstream or downstream gate slots are not included unless they are an integral part of the turbine.

Information on the influence of these parts on the hydraulic behaviour of the turbine may be obtained from tests additional to the model acceptance tests.

For the prototype to reproduce the performance characteristics of the model, the prototype shall be geometrically similar to the model within the tolerances given in Sub-clause 2.4.

2.2.2 *System of dimensional tolerances*

All similarity tolerances refer to permissible deviations between prototype measurements and scaled model dimensions. The model dimension in each case shall be the average of all measurements made of that dimension on the model. The scaled average model dimension is the prototype reference dimension. It is recommended that the model should be made so that individual measurements should not differ from the average by more than the values given in Sub-clause 2.4.

The stipulated tolerances may require modification because of particular model tests which are required (e.g. high head tests) or because of particular manufacturing procedures employed. Such modifications must be the subject of separate agreement.

2.2.3 *Efficiency majoration*

The formulae for majoration of model performance, given in Clause 6 of Chapter VI, are assumed to apply where the geometric similarity of prototype to model falls within the limits set out in Sub-clause 2.4.7.

2.3 *Definitions*

Profile deviation:	The departure of a surface profile from the reference profile (see Figure 1, page 53). For the prototype, the reference profile shall be the average of measured model profiles. When comparing an actual blade profile with a reference profile, the best fit may be obtained by adjusting the angular position of the reference profile.

Waviness: The departure of a surface profile from a smooth curve to which a flexible stick would readily conform. Waviness is expressed as the ratio of maximum departure divided by the distance over which departure from the smooth curve occurs. This is the ratio $\frac{X}{U}$ of Figure 1. In order to distinguish waviness from surface roughness, U should not be less than 50 mm. The point of maximum departure X should lie in the middle third of U.

It should be noted that bumps on the surface are sometimes not as easy as hollows to assess properly as the ratio $\frac{X}{U}$, using a flexible stick. However, bumps can be relatively easily corrected if necessary.

Surface roughness: The characteristic quality of the surface due to small departures from its general form such as those produced by the cutting action of tool edges, abrasive grains and the feed of machine tools.

2.4 *Checking the similarity of prototype and model*

2.4.1 *General*

At least the following parts must be checked to show compliance with the tolerances stated:

- The principal dimensions of the spiral casing, of the stay ring, of the distributor, of the draft tube, of the space between the distributor and runner and of the space between the runner and the head cover when necessary; for impulse turbines, the principal dimensions of the runner and of the casing.
- The principal dimensions of the runner including inlet and outlet diameters, inlet height, runner band and crown. The form of the runner water passages and of the guide and stay vanes; for Pelton turbines, the form of buckets, nozzles and spears and the alignment of the jets to the runner.
- The seal or blade tip clearances on runners and end clearances of guide vanes.

Dimensional checks may be made using templates, clearance templates, by direct measurement or by plotting devices, provided the data so obtained are interpreted in conformity with the following sub-clauses.

2.4.2 *Classification*

Turbines are classified as Francis, Kaplan and Pelton.

The tolerances for Francis turbines apply also to diagonal flow machines.

The tolerances for Kaplan turbines apply also to diagonal flow adjustable blade turbines (Deriaz turbines), axial flow turbines with fixed or adjustable blades (bulb turbines) and fixed blade runners of the propeller type. The tolerances for Pelton turbines can be adapted to inclined jet impulse turbines.

2.4.3 *Runners*

For checking the similarity of prototype and model runners, the following rules apply:

Francis turbine runners

- Blade inlet profiles shall be checked at least at two sections for low specific speed turbines and at three sections for high specific speed turbines. The inlet section shall extend from the nose of the blade a distance 0.1 *D* along both pressure and suction sides of the blade (see Figures 2 and 3, pages 52 and 53).
- Blade inlet angles shall be checked at the same sections as for inlet profiles. Inlet angle shall be measured by taking the inclination of a template extending from the nose of the blade to 0.05 *D* along the blade and located to give the best fit to both sides of the blade simultaneously (see Figure 3).
- Blade outlet profiles shall be measured at least at three sections. On the pressure side, the outlet section shall extend from the tail of the blade a distance back along the blade of 0.1 *D*. On the suction side, the section shall extend from the tail of the blade a distance 0.15 *D* back along the blade (see Figure 3).
- Blade outlet angles shall be checked at the same sections as for outlet profiles. Outlet angles shall be measured by taking the inclination of a template extending from the tail of the blade a distance 0.05 *D* back along the blade and located to give the best fit to both sides of the blade simultaneously (see Figure 3).
- The runner inlet diameter shall be checked at three points (see Figure 2).
- Outlet width between blades shall be checked at least at three points on each blade (see Figure 4, page 66).
- The whole surface of the blades including the defined profile sections and the runner crown and band shall be checked to establish that profiles are smooth continuous curves with a waviness less than 0.02. A flexible stick may be used for this purpose.
- On surfaces subject to cavitation or incipient cavitation, the waviness shall be less than 0.01.

Waviness to these limits shall be allowed only as an isolated defect occurring occasionally on the blade surface.

Kaplan turbine runners

- Blade profiles shall be measured at least at three sections on both pressure and suction sides of the blade.

  The nose profile of each of the measured sections shall be checked. The nose profile shall extend from the nose of the blade a distance 0.05 *D* along the blade (see Figure 6, page 19).

  In making these checks, the best fit between blade and each reference profile may be obtained by rotating the reference profile provided the angular adjustment of the reference profile does not exceed ±0.25° and the axial adjustment does not exceed ±0.2% *D* compared with the correct location of the reference profile. These adjustments shall be allowed only once for each section and all check measurements made simultaneously on both the pressure side and the suction side of the section considered (see Figures 5 and 6, pages 67 and 68).
- The whole surface of the blades, including the defined profile sections, shall be smooth with a waviness of less than 0.03.

  On surfaces subject to cavitation or incipient cavitation, the waviness shall be less than 0.01.

Waviness to these limits shall be allowed only as an isolated defect occurring occasionally on the blade surface.

- With the blades mounted in the hub, the inclination of the blades with respect to each other shall be checked. For this purpose, the inclination of the outer measured profiles shall be compared. The difference in inclination between the highest and lowest blades shall not exceed 0.25°.

Pelton turbine runners

- The profile of each bucket shall be checked at least at four transverse and four longitudinal sections (see Figure 7, page 69).

- The discharge angles *β* of each bucket shall be checked at four points on each side (see Figure 7).

- The form of the cutout, the angle *γ* of the back of the cutout, the splitter edge and the bucket inclination *α* shall be checked on each bucket.

- The bucket inside width and the bucket outside profile shall be checked, the tolerances in this case being nominal and chosen only to ensure that no more interference can occur on the prototype than on the model.

2.4.4 *Guide vanes*

The nose and tail profiles shall be measured at least at two sections over a distance extending to 0.2 of the vane length.

2.4.5 *Seal and guide vane end clearances*

The seal clearances, blade tip clearances and guide vane end clearances on reaction turbines shall be checked.

The prototype clearance shall not exceed the scaled model clearance under operating conditions.

2.4.6 *Surface roughness*

The actual efficiencies realized by both model and prototype turbines are affected by the roughness provided on all hydraulically significant surfaces. A model operating on a low head may be hydraulically smooth, while the roughness of most significant prototype components is normally not hydraulically smooth. The prototype roughness adopted must be the subject of agreement since the best solution depends upon the economic value of efficiency, cost of manufacture, machine size and on whether site conditions are likely to be damaging to surface finish. Hydraulically rough surfaces reduce the efficiency below that which is potentially obtainable.

Moreover, the finish required may be chosen at some points to improve cavitation resistance or for fatigue strength reasons and the choice is then not related to model-to-prototype dimensional similarity.

The following table indicates guidance values of prototype surface roughness. Good surface finish may be specified when warranted by the economic value of efficiency. When erosion due to sand, etc., is likely to deteriorate surfaces quickly, the initial provision of a fine finish is probably not warranted.

Surface roughness *Ra* (μm) (centre line average)	Application
0.8– 1.6	Pelton runners inside of buckets
1.6– 6.3	Medium to high head Francis runners
6.3–12.5	Low head Francis or Kaplan runners; medium and high head guide vanes
12.5–25	Low head guide vanes, stay rings

The surface roughness may be checked by tactile comparison with standard sample plates prepared by a similar machining process.

A head of 100 m should be taken as the boundary between low and medium head as usec in the above table.

2.4.7 *Deviations in geometric similarity*

	Permissible maximum deviations, prototype measurement to reference	Recommended maximum deviations, individual model measurement to average model measurement
Principal dimensions of hydraulic passages		
Metallic and concrete passages and casings	±2%	—
Stay ring	±2%	—
Distributor height	±0.4%	—
Clearances		
Seal and guide vane end clearances	Equal to or less than reference	
Guide vane profile		
Individual	±5% *T*	±3% *T*
Average	±3% *T*	—
Francis runners		
Inlet section profile	±0.1% *D*	±0.1% *D*
Inlet pitch P_i	±0.5% *D*	—
Inlet angle:		
individual	±3°	±1.5°
average	±1.5°	—
Outlet section profile	±0.1% *D*	±0.1% *D*
Outlet angle:		
individual	±2°	±1°
average	±1°	—
Outlet width:		
individual	+5% *a*	±3% *a*
	−3% *a*	—
average	+3% *a*	—
	−1% *a*	—
Principal runner dimension	±0.25%	—
Inlet diameter:		
individual	±0.5% *D*	—
average	±0.25% *D*	—
Kaplan and diagonal flow runners		
Blade profile	±0.2% *D*	±0.2% *D*
Nose profile	±0.1% *D*	±0.1% *D*
Runner chamber	±0.2% *D*	—

	Permissible maximum deviations, prototype measurement to reference	Recommended maximum deviations, individual model measurement to average model measurement
Pelton turbines		
Spear and nozzle diameter:		
individual	±0.3% *d*	—
average	±0.3% *d*	—
Spear and nozzle profile:	±1% *d*	—
Nozzle angle:		
individual	±1°	—
average	±1°	—
Spear angle:		
individual	±2°	—
average	±2°	—
Bucket inside width *	−0%	—
Bucket outside profile *	+0%	—
Bucket internal profile	±0.5% *W*	±0.5% *W*
Bucket inclination α:		
individual	±1°	±1°
average	±1°	—
Bucket discharge angle β:		
individual	±1°	±1.5°
average	±1°	—
Cutout profile	±1% *W*	±1% *W*
Angle of face at back of cutout γ:		
individual	+0°	±1°
	−3°	—
average	+0°	—
	−3°	—
Jet circle radius	±0.2% *D*	—
Alignment of jet to runner	±0.5% *W*	—

Symbols used and definition

T = maximum thickness of guide vane for each measuring section

D = runner inlet diameter at mid-height of vanes at inlet for Francis turbines (see Figure 2, page 64)

overall diameter of blades for Kaplan and diagonal flow turbines (see Figure 5, page 67) or jet circle diameter for Pelton turbines

P = blade inlet pitch for Francis runners (see Figure 3, page 65)

d = nozzle orifice diameter (see Figure 7, page 69)

W = bucket maximum internal width (see Figure 7)

a = outlet width = the minimum width between measuring point on outlet edge of one blade and the adjacent blade (see Figure 4, page 66)

Note. — Irrespective of tolerances stated, it is not normally possible to manufacture a model by hand finishing to have profiles better than ±0.2 mm.

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* These tolerances are intended only to ensure that water interference on the back of the bucket is not greater on the prototype than on the model.

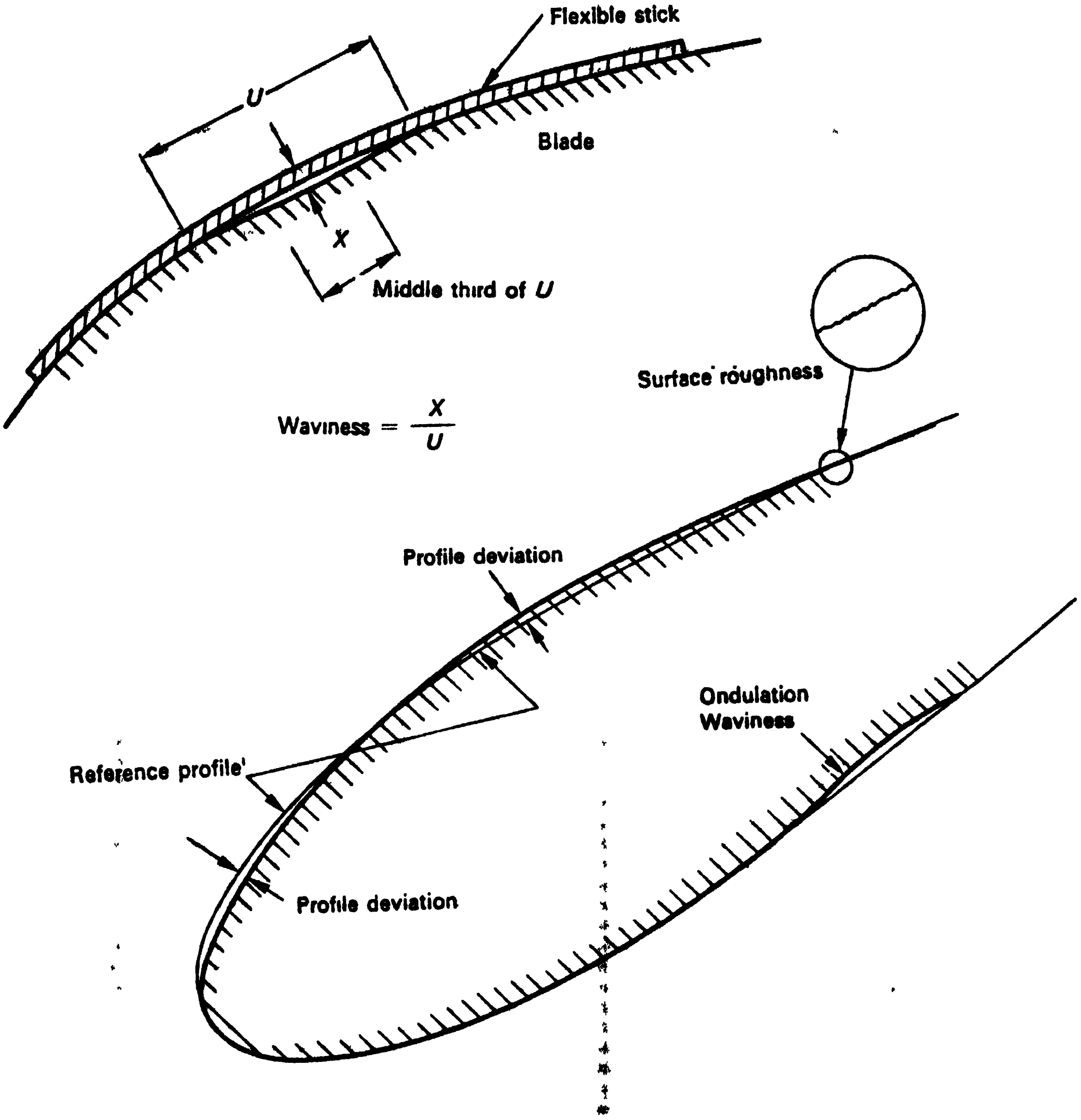
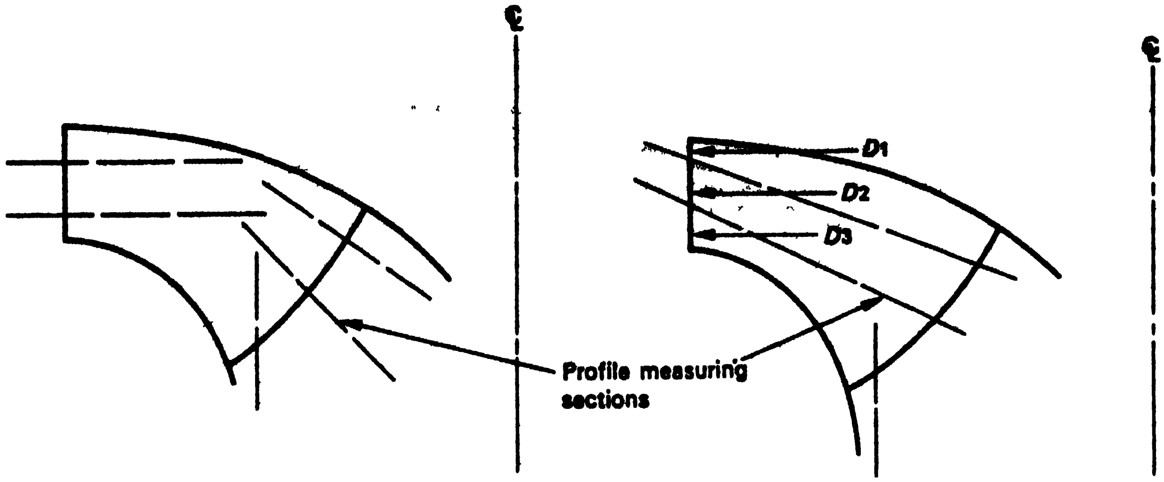
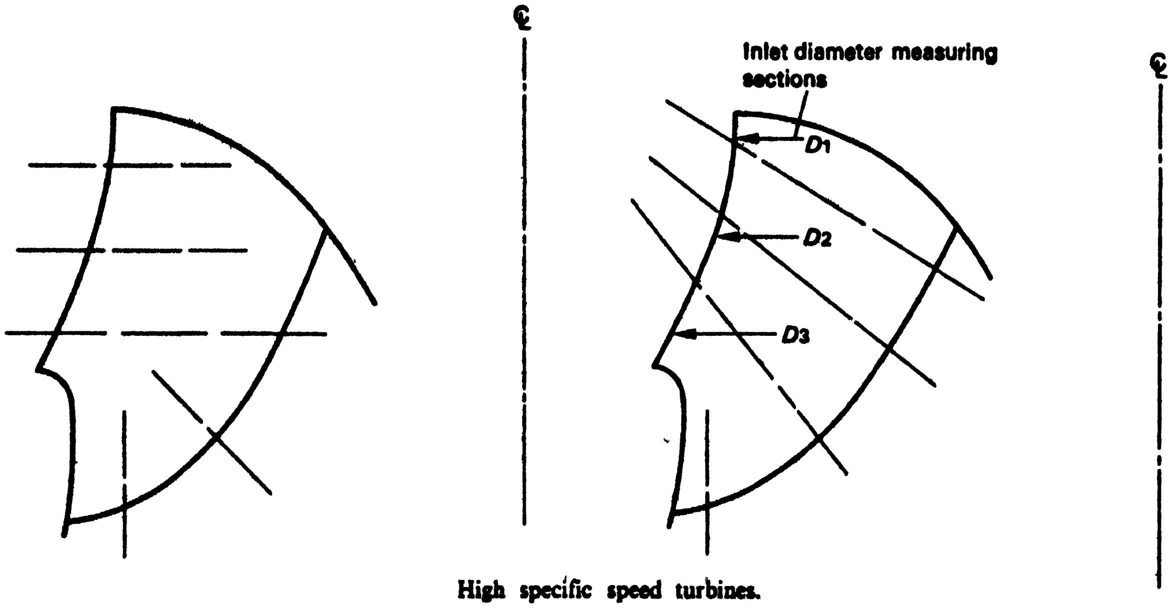


FIG. 1. — Definition of waviness, surface roughness and profile deviation.



Low specific speed turbine.



High specific speed turbines.

Note. — Blade profile measuring sections may be either plane or conical sections.

FIG. 2. — Francis runner blade profile measuring sections.

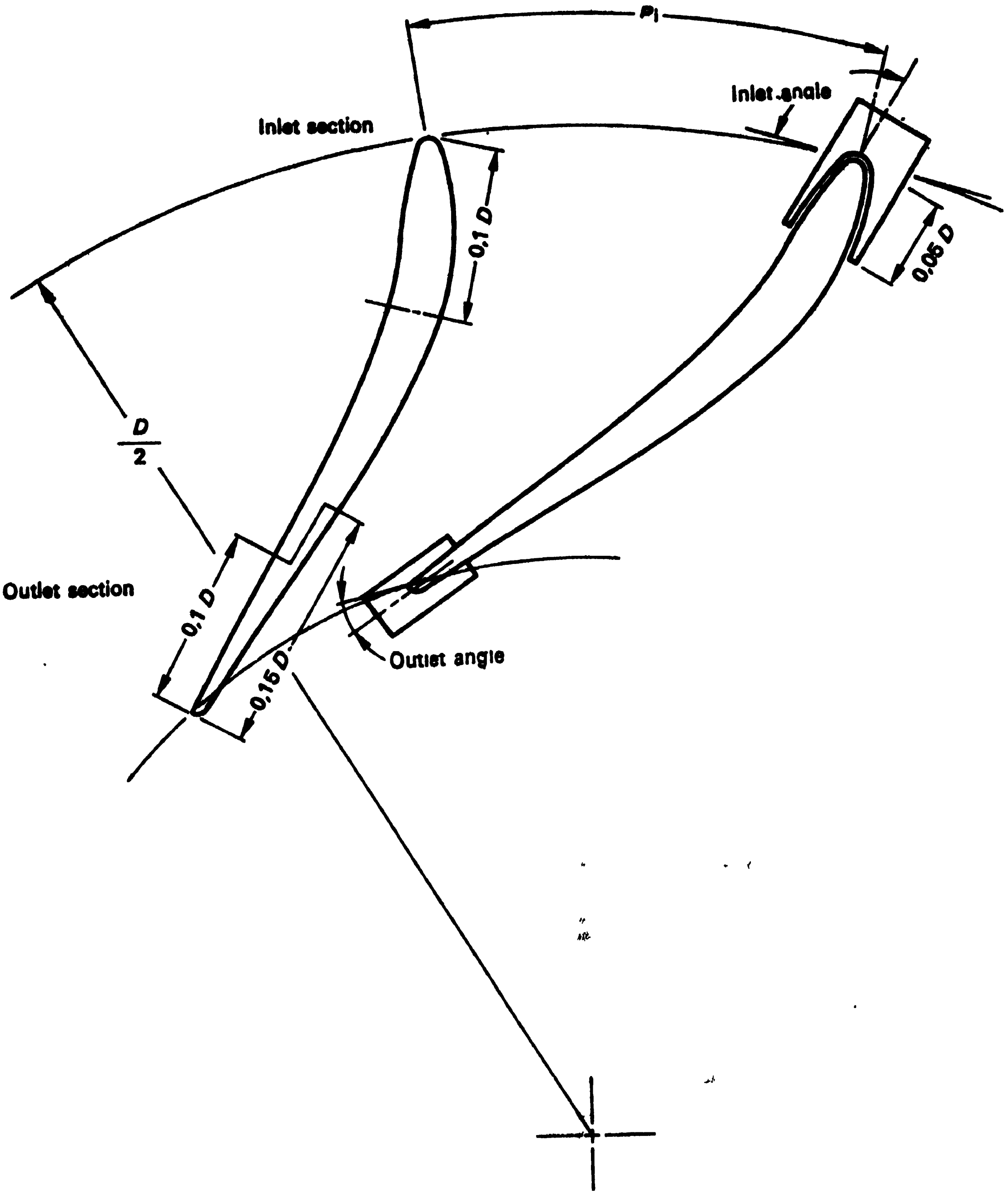


FIG. 3. — Francis runner definition of measuring sections.

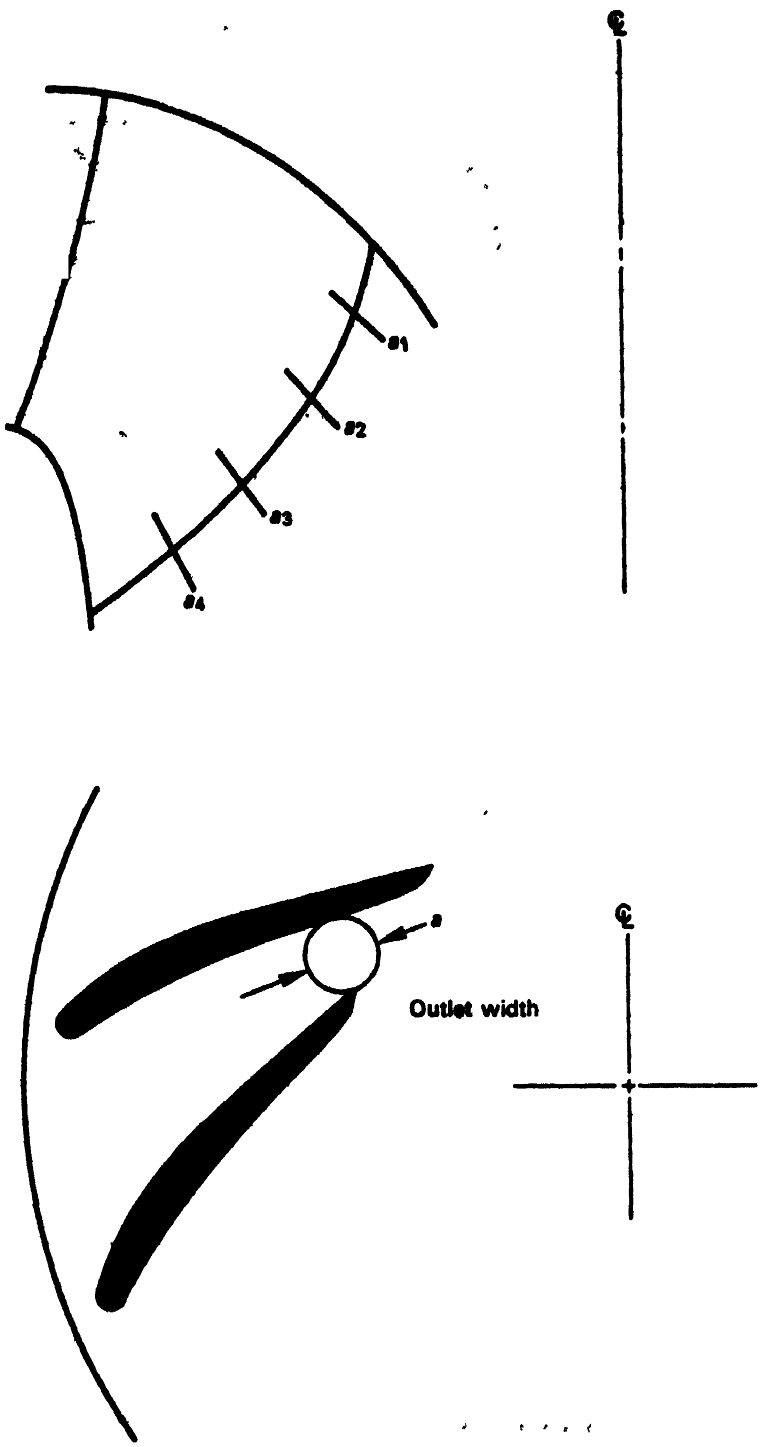
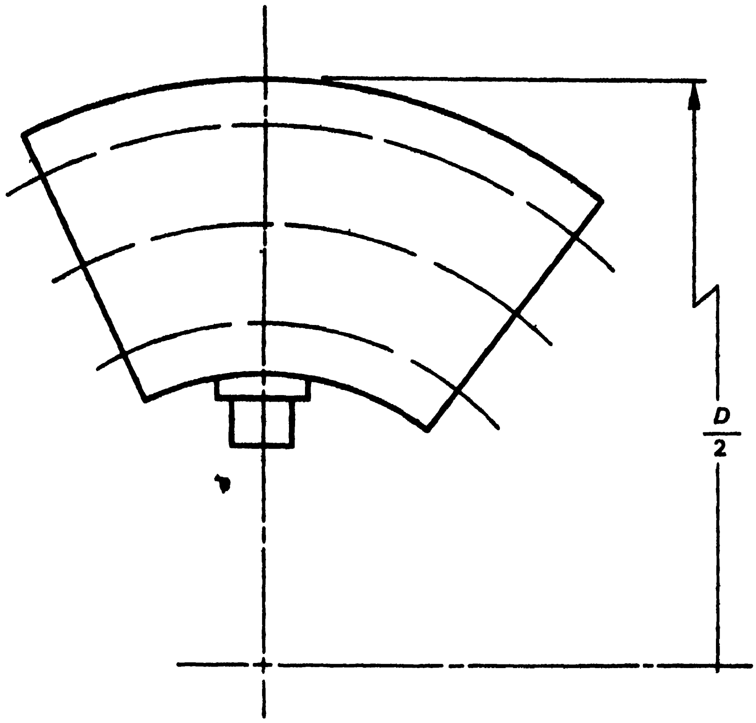
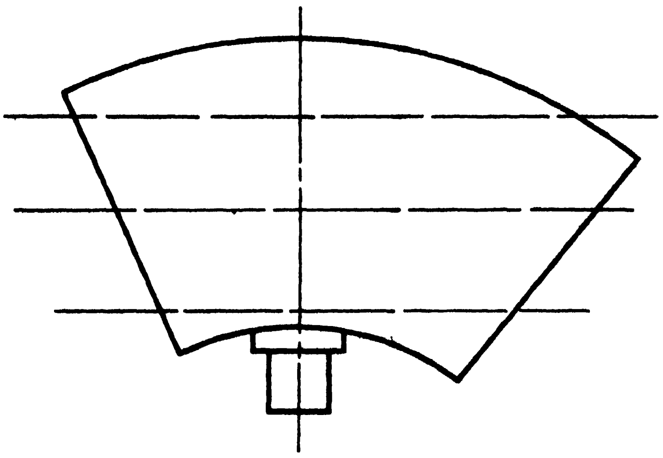


Fig. 4. — Francis runner definition of outlet width.



a) Cylindrical sections.



b) Straight sections.

Fig. 5. — Kaplan and diagonal flow turbine blade profile measuring sections.

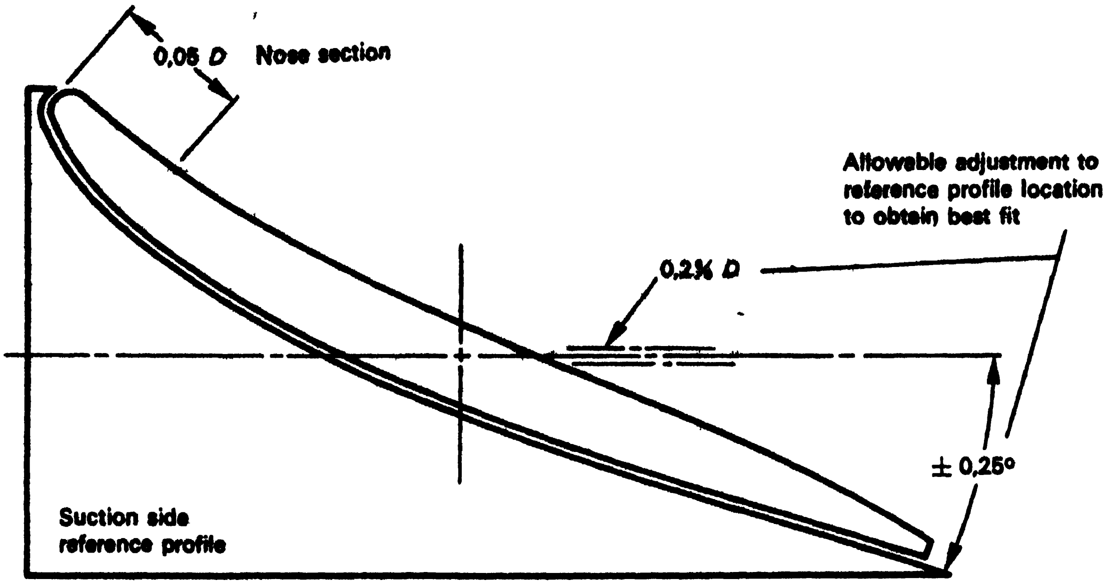

0,05 D
Nose section
Allowable adjustment to reference profile location to obtain best fit
0,2% D
± 0,25°
Suction side reference profile

FIG. 6. — Kaplan runner definition of measuring sections and tolerances.

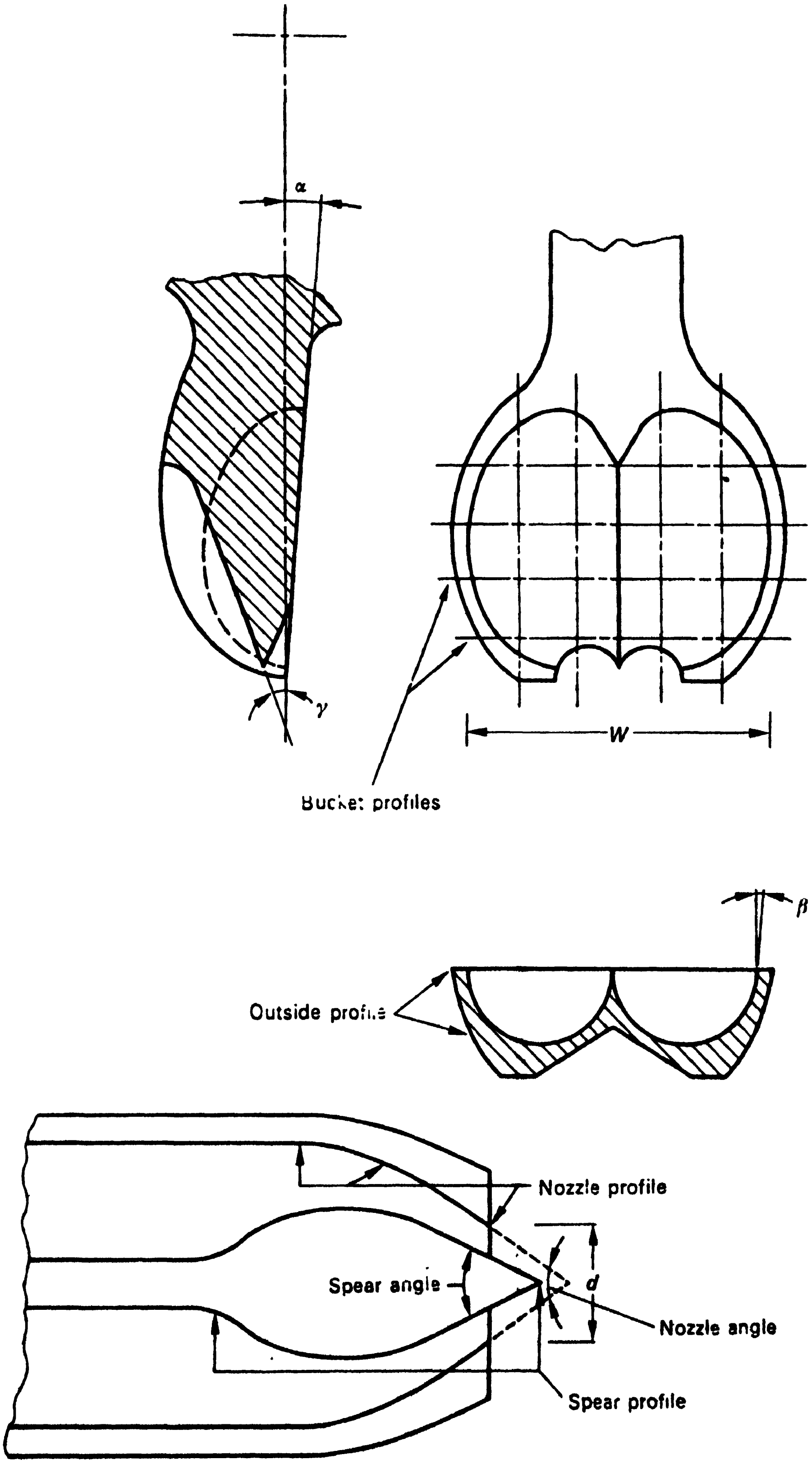


FIG. 7. -- Pelton turbine definition of measuring sections.

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NATIONAL FOREWORD

This Indian Standard which is identical with IEC Pub 193 (1965), issued by the International Electrotechnical Commission (IEC), was adopted by the Bureau of Indian Standards on the recommendation of the Rotating Machinery Sectional Committee (ET 15) and approval of the Electrotechnical Division Council.

The text of IEC Standard has been approved as suitable for publication as Indian Standard without deviations.

Only the English language text given in the International Standard has been retained while adopting it as Indian Standard, and as such the page numbers given here are not the same as in IEC Publication.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

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